IBA TECHNICAL REVIEW

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Transmitter Operation and Maintenance

IBA INDEPENDENT BROADCASTING AUTHORITY

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6 Transmitter Operation and Maintenance

Contents

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NOTE:

Code of Practice for the Technical Performance of Television Transmitting Stations.

Under the terms of the Independent Broadcasting Authority Act 1973 the IBA is required to ensure that high quality technical standards are provided and maintained. The Authority's Code of Practice for the Technical Performance of Television Transmitting Stations, which is referred to in the following articles, sets out the tolerances and standards to be aimed for on a day-to-day basis. The Code is reproduced in *IBA Technical Review 2: Technical Reference Book*.

Additional Copies

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No charge will be made for small quantities.

IBA

INDEPENDENT BROADCASTING AUTHORITY

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Broadcasting: A Public Service

by R C Hills
Chief Engineer (Transmitters)
Independent Broadcasting Authority

Anyone who cares to look through a selection of the current technical press would find it hard to believe that any worthwhile engineering is carried on outside the walls of the research and development laboratory, be it of a large company, or at one of our Universities. It is an unfortunate fact of life that the glamour and excitement of technology are always associated with innovation and discovery, and often little attention is paid to the 'grass-roots' engineering on which the technology is founded and which is the usual incentive for research and development. Much has been published elsewhere, and in preceding issues of this Review, about the development work so effectively carried out in the laboratories of the IBA. The many successes such as the digital field-rate standards converter known as DICE (Digital Intercontinental Conversion Equipment), the teletext transmission system ORACLE (Optional Reception of Announcements by Coded Line Electronics) and the systems of computer monitoring have been rightly accorded the recognition they deserve. The work of IBA research engineers is studied with interest by broadcasters throughout the world and there is a regular exchange of views at international level.

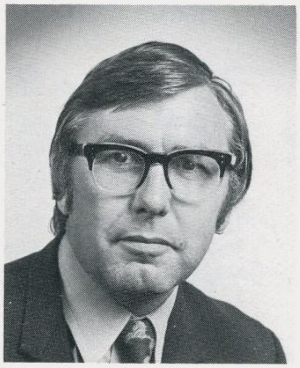
But, exciting and necessary as it is, this innovatory work stands beside the primary engineering function of the IBA which is that of transmitting a television service regularly to (in the words of the Independent Broadcasting Authority Act 1973) '. . . so much of the United Kingdom, the Isle of Man and the Channel Islands as may from time to time be reasonably practicable'. The quality of the programmes produced by the 15 Independent Television programme companies, and the reliability of service which the viewing public in this country have come to expect, are of an order which I am confident will bear comparison with any other television service in the world. In addition, the Independent Local Radio service, which from early 1976 provides programmes from 19 separate companies, is transmitted simultaneously on MF and, in stereo, on VHF.

In these fields of regular television and local radio broadcasting, the Authority has introduced many innovations. It pioneered the use of Band III for television transmission in the 1950s when little was known of the propagation characteristics for providing such a service. Then in 1967, when Government approval was forthcoming for ITV to be broadcast in colour and in the UHF bands, the Authority planned from the outset that this new network of UHF transmitters would be completely automatic and unattended in its operation; and at the time of its opening in 1969 the IBA's London station at Crystal Palace was the highest-power unattended UHF television transmitter in the world having an ERP of 1MW. Since then, the continued growth of the UHF network has led to the introduction of even more sophisticated systems of control and monitoring with the object of keeping to a minimum the number of staff needed for its operation. In the field of radio transmission the IBA was, in 1973, first in Western Europe to make extensive use of highly directional MF aerial arrays to permit the re-use of scarce MF channels, and pioneered the introduction of circularly polarised VHF stereo radio to improve reception on portable receivers, especially car radios.

The day-to-day operation of large television and radio networks relies heavily on mobile maintenance staff. But behind this must exist an organisation concerned with recruitment and training, with staff relations and safety, with the statistical analysis of the network performance, with the overall maintenance policy and with its corollary – the systematic modification and improvement of transmission plant. The collection of papers in this issue of the *IBA Technical Review* describes how such an organisation has evolved within the Authority, which this year celebrates the 21st anniversary of programme transmission, and explains some of the engineering philosophies. It also underlines the IBA's claim to provide one of the most cost-effective and publicly acceptable UHF colour television services in the world.

HARRY BOUTALL, MBE, CENG, MIEE joined the Authority in 1955. Prior to this he was with the BBC where he had been successively employed in the Lines Department, the Designs Department and the Planning and Installation Department. For the first 14 years of his service with the Authority his work was related to transmitter station design and construction. Then, in 1969, he was appointed to his present post of Head of Station Operations and Maintenance Department.

PETER MASSINGHAM, CENG, MIEE, joined the Authority in 1958 after having been employed in the Post Office Engineering Department. He was successively assigned to the maintenance staff at three of the Authority's transmitting stations and moved to Headquarters in 1966. In 1971, having an interest in statistics, he was given the task of forming the Methods and Operations Unit responsible for the collection and analysis of data concerning transmitting station performance, with particular attention to maintenance effort required.



The Operation and Maintenance of the IBA Transmitter Network

by H W Boutall and R P Massingham

Synopsis
To maintain efficiently the growing IBA network of television and radio transmitters, scattered over the length and breadth of the United Kingdom and already amounting to a total of well over 285 installations, calls for careful planning and a clearly defined staffing policy. At the present time there are about 250 engineers whose job it is to monitor, operate and maintain this network from 23 locations, including 14 Regional Operations Centres. It is now planned that during the current decade all those IBA transmitting stations not already unmanned will be converted to unattended and automatic operation, and that the number of Regional Operations Centres will be reduced from 14 to 4. The monitoring staff thereby released will go towards building up an increased number of mobile maintenance teams.

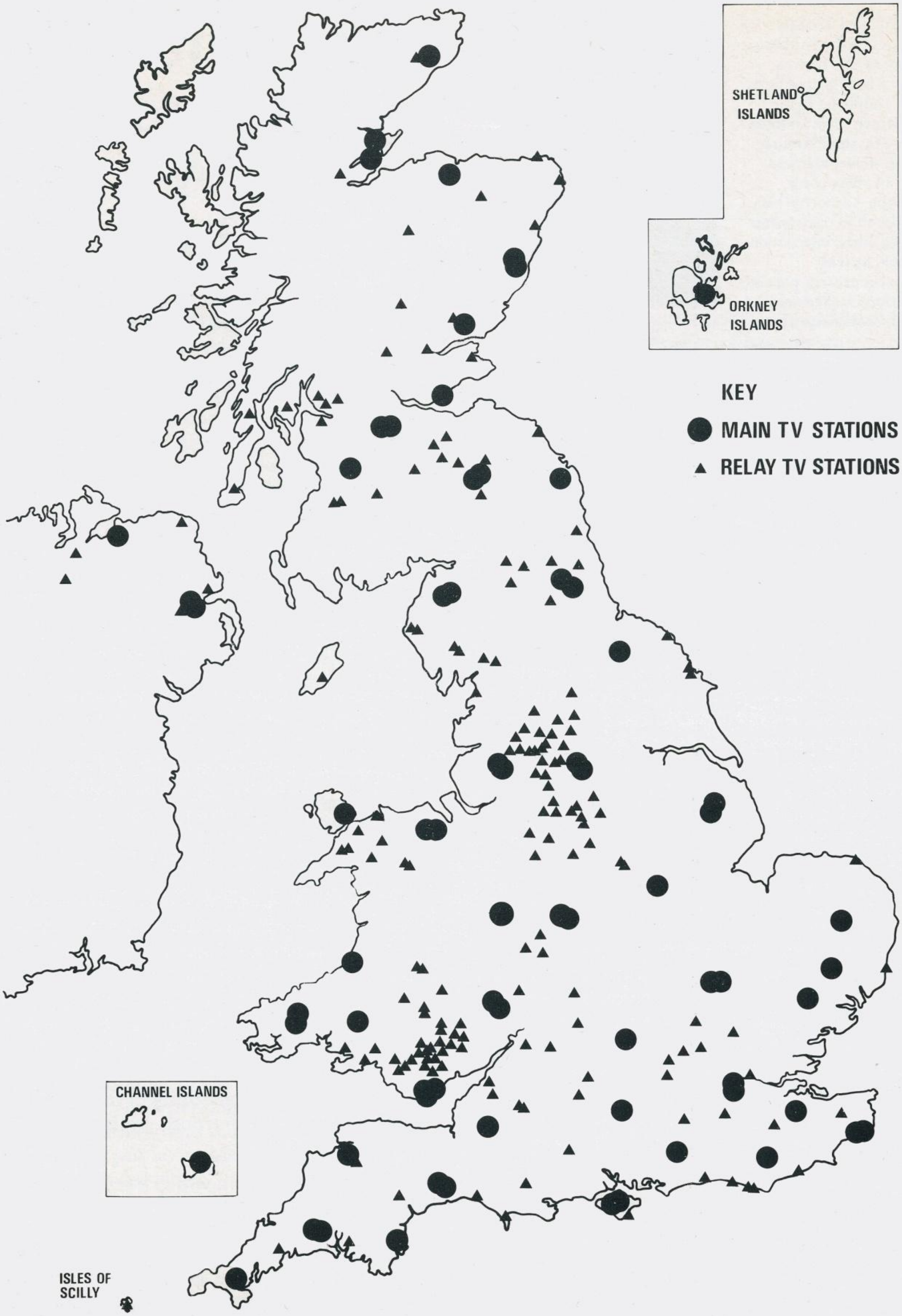
To assist in identifying areas of unreliability and to ensure that failures are promptly and effectively dealt with, a system has been introduced based on a Station Day Report being completed by the maintenance staff. The collation and analysis of results so obtained is undertaken with the aid of a computer.

Introduction

The IBA operates regional television services which are broadcast simultaneously in the VHF Band III, using the 405-line monochrome system, and in the UHF Bands IV and V on 625 lines and in colour. It also provides a number of Independent Local Radio services (see the *IBA Technical Review 5*) which in any given location are simultaneously available in MF-AM and VHF-FM, the latter having stereo capability. By the early part of 1976 the IBA will have in service 39 local radio and over 250 television transmitter installations, see Fig.1, and by 1980 this latter figure will have risen to at least 450.

This article mainly describes the task of maintaining satisfactory service from these television transmitters, and of ensuring the availability of the necessary staff and resources for this purpose, both now and in the future.

There are many ways in which a service can be deemed satisfactory, the major one probably being that of public acceptance. However, more objective assessments are needed for planning purposes and, in engineering terms, these are expressed by the Breakdown Record, which gives a measure of


SHETLAND ISLANDS
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reliability, and the maintenance limits, which provide a measure of quality. Tables 1, 3 and 4 give target figures for these assessments in the case of television, and Table 2 indicates the minimum performance limits for the major parameters.

The IBA differs from most broadcasting organisations in that it does not originate its own programmes, neither does it operate the inter-city network of transmission links. Yet it is responsible for the technical quality of the transmitted signal. It is, therefore, very necessary that overall performance objectives are apportioned to the various parts of the transmission chain from studios to transmitters. Target figures for the separate sections are given in the IBA Codes of Practice contained in the *IBA Technical Review 2.*

These targets must be met with minimum cost, consistent with the need to comply with relevant Government and statutory regulations and agreements entered into with trade unions.

The IBA transmitting stations are located throughout the United Kingdom and about 250 engineers are employed to operate, maintain and, where applicable, monitor them. Groups of between four and 18 engineers, including mobile maintenance personnel, are based at 23 sites which are mainly those of the older VHF television stations. The later VHF and all the UHF television stations, as well as all the radio stations, have been designed for automatic and unattended operation.

The country is divided into four engineering regions – South, Central England and Wales, North, and Scotland and Northern Ireland. Each of these is under the control of a Regional Engineer who is responsible for day-to-day operation within his region.

All the central planning functions, i.e. staffing levels, equipment programmes, training needs, operation and maintenance procedures, test methods and equipment, spares and inventory levels, recruitment, expenditure and staffing forecast, are co-ordinated at the Authority's Engineering Headquarters at Crawley Court, near Winchester. The regional staff participate fully in this planning work.

Finance

The major items of cost are those relating to staff salaries, electricity and the replacement of components. This latter is largely determined by the station design and the type of equipment installed, but some economies can be made by keeping a constant check on the usage of components and adjusting the spares holdings accordingly, and, in extreme cases, either by replacing equipment or by modifying its design.

However, it is the staff costs which offer the greatest opportunity for economies since these costs are large and can be expected to represent the greater proportion of the total. Staff costs are influenced by the equipment specifications, the performance limits adopted, the amount of stand-by equipment installed, the organisation of duties, and the location of staff. The IBA has given a qualified 'no redundancy' guarantee to its station engineering staff. Therefore, economies in this area can be made only in the long term by re-allocating duties to avoid growth of numbers with increasing workload, and/or by taking advantage of resignations, retirements, etc., to reduce numbers where possible.

Operations

In order to minimise the duration of service breakdowns, it is necessary to know promptly when breakdowns have occurred, so that early action can be taken to restore transmissions. It would be too expensive to have for each type of station a reporting system which responded immediately to every type of fault. The stations have therefore been classified in relation to population coverage, and appropriate reporting time allocated to each classification. Table 3 details these. Telemetry systems are used for this purpose, operating over Post Office private or subscriber circuits, the choice being determined by the allocated reporting time. For the very small television stations, no telemetry is used, and reliance is placed on selected dealers to report faults.

The output of each of the programme companies, which are under contract with the IBA to provide the programmes in each of the different regions, is

Table 1
BREAKDOWN TARGETS

STATION TYPE	TARGET
Main Stations (Transmitters)	<0·5% of programme time averaged over a 4-week period
Relay Stations (Transposers)	<0·2% of programme time averaged over a 4-week period

Fig.1. Map showing the distribution of the 245 television transmitting installations (VHF and UHF) that were in operational service by the end of 1975.

Table 2

SYSTEM MAINTENANCE LIMITS

SYSTEM MAINTENANCE LIMITS		MAIN STATION	MAIN STATION +*RBL Main Stn.*	MAIN STATION +*Transposer*	MAIN STATION +*RBL Main Stn.* +*Transposer*	MAIN STATION +*2 Transposers*
Power output, sound and vision relative to nominal		±1dB	±1dB	±2dB	±2dB	±2dB
Modulation level	Blanking level	74·78%	74·78%	72·80%	72·80%	71·81%
	Peak white level	17·23%	16·24%	16·24%	15·25%	15·25%
2T pulse response		2·5%K	3·5%K	3%K	4%K	4%K
10*us* bar response		1·5%K	2%K	2%K	2·5%K	2·5%K
Chrominance-luminance gain inequality		±7%*	±15%*	±15%*	±20%*	±20%*
Chrominance-luminance delay inequality		40±20ns	60±60ns	40±40ns	60±60ns	40±60ns
Non-linear distortion, luminance signal		7%	10%	10%	13%	13%
Differential gain		7%	10%	—	—	—
Differential phase		6°	10°	—	—	—
Noise on line 22		—	–44dB	–44dB	–44dB	–44dB
Subjective sound quality		Grade 2	Grade 2·5	Grade 2·5	Grade 3	Grade 3

**If receivers employing envelope detection, as opposed to synchronous detection, are used in the transmission system, limits for 2T pulse-to-bar K rating and chrominance-luminance gain inequality are modified. For each envelope detector in the system, the ideal bar amplitude is increased by 5%, relative to the pulse and the chrominance amplitude reduced by 4%. The maintenance limits for these two parameters do not include these inherent distortions and should be modified accordingly.*

Table 3

MONITORING LEVELS RELATED TO STATION CLASS

CLASS OF STATION	POPULATION SERVED (*Thousands*)*	TIME FOR WHICH FAULT MAY EXIST UNDETECTED: 'CATASTROPHIC' FAULT	PICTURE IMPAIRMENT WORSE THAN STATED GRADE
A	250 (20%)	As short as possible	10 mins – Grade 2
B	50–250 (5–20%)	10 mins	30 mins – Grade 3·5
C	5–50 (1–5%)	10 mins	8 hours – Grade 3·5
D	1–5	8 hours	24 hours – Grade 3·5
E	1	8 hours	48 hours – Grade 4·5

**or percentage of programme company's service including dependent stations*

Table 4

ATTENDANCE TARGETS

STATION TYPE	TARGETS *(Manhours per 4-week period)*
UHF main stations (>6kW)	<45
UHF relay stations (1kW)	<25
UHF relay stations (200W)	<15
UHF relay stations (50W)	<10
VHF main stations (>4kW)	<45
VHF relay stations (1kW)	<30
VHF relay stations (50W)	<10
SHF link stations	<10

monitored at the common feed point relevant to those transmitters which it feeds. Currently there are 14 such centres, one for each region, which are manned throughout most of the hours of broadcasting.

Maintenance

The ability to meet transmission 'targets' depends largely upon the maintenance policies adopted. It is necessary to be able to identify areas of unreliability, and to ensure that staff of the right calibre, and of sufficient quantity, are equipped with the right test equipment, and are in the right place at the right time. To assist planning of all these aspects, a comprehensive reporting system has been introduced based on a Station Day Report, which is completed by the maintenance staff.

This report identifies the equipment and/or sub-unit which has been maintained, details the components which have been replaced, and records the amount of time spent on maintaining each sub-unit of equipment. The information is collated and analysed to reveal the incidence of unreliability, and to indicate which items of equipment require most attention. It is then possible to introduce modification programmes to improve reliability where this is most needed, to identify training needs, and to show inadequacies in documentation and/or test methods and equipment. Hitherto, information systems of this type have proved unsuccessful because of the large clerical effort required. The computer has eliminated this difficulty, and the success of the system is now determined largely by the accuracy with which each report is completed by the maintenance staff. To achieve the required accuracy it is important that the staff recognise positive benefits resulting from the system either, for example, by a noticeable improvement in reliability or by a simplification of alignment procedures.

To ensure that the targets for quality of transmission are achieved, the performance of each station is checked by visiting mobile maintenance teams. The test signals, which are inserted on lines in the field blanking, are used for these measurements. These afford the opportunity of discovering drifts in performance, but if more detailed information is required, because of suspected long-term drift and/or intermittent faults, then automatic logging equipment is used for monitoring over a longer period.

Until recently, stations have been visited only on report of a fault, but preventive maintenance has now been re-introduced in the belief that it will lead to an improved performance of the network, and a reduction in the total maintenance effort required. The Station Day Report System will enable the results to be measured.

Each mobile maintenance team consists of two engineers on duty at any given time, and is equipped with sufficient test equipment to enable a full alignment of a transmitter to be undertaken if necessary. (See separate article in this volume).

Many small stations can be approached only via unmade roads or tracks, and teams maintaining such stations are supplied with Range Rover vehicles. Should a site be such that access with a Range Rover is impossible, a set of the necessary test equipment is permanently allocated to the station, and/or a special tracked vehicle is used.

The base locations of the mobile maintenance teams are in many cases predetermined by the staffing policy which was adopted for the early VHF stations. These stations were manned, and each was provided with offices, staff room, kitchen, garages, stores and a workshop. They are therefore used for this further purpose even though they may not be in optimum positions with respect to the teams' workloads.

The number of stations which can be serviced by any single team is dependent upon the types of station in the area for which that team is responsible, and the distances to be travelled. Table 4 shows the on-site attendance targets for stations of each type.

When a new station is commissioned, its allocation to a maintenance area is determined by the distance and the type of terrain to be covered, the type of equipment, the loading effect on the teams and the forecast of future growth of maintenance load in that area. Where teams are likely to be overloaded, the options are either to increase the number of teams at the base, or transfer part of the load to another base, or establish a new base more centrally within a

concentrated area of the workload. The decision is more than a matter of logistics; it is influenced by staff attitudes and the amount of inconvenience caused. For instance, staff might prefer to accept longer journeys, with nights away from home, rather than move to a new area with consequent disruption to their family life. These factors must be considered and the optimum solution might have to be sacrificed, provided that the cost of the alternative remains reasonable.

Staff Planning

Planning is directed mainly at containing or reducing the number of field staff even though the number of stations is constantly growing. This is because staff represent the largest cost category. As, during the early years of independent television, the number of transmitting stations increased so also did the number of operational staff, but since the introduction of unattended stations in 1961 the number of staff has remained constant by redeploying for maintenance work those formerly employed in monitoring and operational duties. This policy will be continued during the current decade by converting *all* stations to unattended and automatic operation, and by reducing the number of manned Regional Operations Centres from 14 to 4. This will necessitate that the signals from most of the television programme companies will be monitored over-air, and monitoring of the transmitter network will be accomplished by automatic methods. The number of staff currently undertaking these operational duties will eventually be reduced by approximately 80. The release of this number of monitoring staff for other duties is not expected to be sufficient to fill the vacancies arising from resignations, retirements and transfers to other departments, nor to meet the expected growth in the number of maintenance teams. Therefore, it will be necessary to recruit new staff during this period.

It is not usually possible to recruit experienced staff for this work. The practice has therefore been to recruit staff at the trainee level who then undergo an 18-month period of training. An important consequence of this training period is that errors in staffing forecast cannot normally be corrected in less than two years. This places great importance on the accuracy of the planning and the station growth forecast.

The redeployment of staff for maintenance duties creates the need for providing specialised training in equipment and maintenance techniques. The IBA has its own Training Unit which is being developed to meet these specialised needs, although full use of manufacturers' courses is made and will continue.

Industrial Relations

As stated above, the logistics of planning in terms of staff numbers, locations, etc., must always show consideration for the views of staff, usually as expressed through the medium of trade unions. One of the main objectives of any trade union is that of securing the conditions most favourable to its members, and in pursuance of that, it will endeavour to extract every advantage and benefit from any plan or forecast made. Therefore, if plans are to be pursued effectively, it is essential that proposals be discussed with the union at an early date, so that ample time is available for negotiation before changes need be implemented. It is also important to retain flexibility in the planning so that the plans can, if necessary, be modified to respond to any valid objection or alternative proposal which the union may advance. Failure to give ample time or to adopt a flexible approach could, in the present climate of industrial relations, lead to a situation of confrontation and frustration. The art of management begins when the logistic planning ends.

The Information System

The organisation described above has evolved over several years, and is as a direct consequence of a change in operating philosophy coupled with a multifold increase in the size of the network.

During the last five years the IBA has moved from a 'monitoring and base maintenance' type of operation, to essentially a 'mobile maintenance' type of operation. This has been possible because certain advances in technology have provided more stable and reliable equipment, and have made available automatic monitoring, remote control and supervisory systems. There is, therefore, less need to monitor manually the transmitter network, and this is reflected in changes made in the organisation during the recent past, and in others planned for the future.

Accordingly, the Station Day Reporting System was introduced and its value has been twofold. First, its most important contribution has been in the area of long-term planning enabling the growth in the workload of maintenance teams to be anticipated and the siting of these teams and the allocation of their workload to be optimised; second, it has enabled experience to spread throughout the network, thus achieving overall improvements in reliability, rapid identification of trouble areas and simplification of procedures. In consequence, it is now possible to plan with detailed knowledge which is constantly being updated as equipment becomes more reliable and the maintenance staff become more skilled in their duties.

This ability to measure the performance of the system implies that it can be perfected and controlled. Panic situations involving *ad hoc* allocation of resources can be avoided. And, it is hoped, by creating a professionally managed system, the objective of providing the best possible working arrangements for staff can be fulfilled.

Future Developments

It is to be expected that automatic techniques in the areas of fault diagnosis and analysis, aided by the computer, will find increasing application. Modular design of equipment will increase, so that lengthy on-site work can be avoided and specialised repair work will be performed at central workshops. It is also reasonable to assume that equipment will become more reliable and that a meantime between failures of two years or more should become possible, and with the increasing stability of equipment it is likely that the need for human monitoring will disappear altogether. These changes will have considerable effects on staffing policy, and will need careful introduction if hardship to staff is to be avoided.

There are also other factors which could cause a change in methods, such as Government legislation, a revolution in technology or a serious energy shortage. These are all nebulous possibilities, and planning in anticipation of them would be fruitless. But any of them could be totally disruptive to any long-term plan. This is not to advocate that long-term planning should not be taken seriously, but merely to dispel disillusionment when events take a different and unforeseen course, 'The best laid schemes o' mice an' men . . .'.

Summary

An outline of the methods and targets employed by the IBA for the satisfactory operation and maintenance of a transmitter network have been given, together with some thoughts for the future, and an indication is given of the wide range of technical, geographical and staff factors which need be considered.

The IBA's approach to three specific problem areas is described in greater detail in the following appendix.

APPENDIX

1. The Siting of Mobile Maintenance Teams

Given a network of UHF/VHF television, and VHF/MF radio transmitting stations, it is necessary to decide how it should be serviced and maintained. The IBA have chosen to operate it as an unattended network and have decided that it be maintained by mobile maintenance teams sited at bases throughout the United Kingdom. The problem is to decide the most suitable locations for these bases and the number of teams that should be assigned to each.

The approach to the problem could be that of linear programme techniques. By knowing the positions and workloads of all stations, it is possible to calculate the distance from each station to any assigned mobile maintenance base and thus to determine the travelling time. The availability of work effort from each mobile maintenance team is also known, but there is a multiplicity of ways of allocating stations to mobile maintenance bases, and linear programming techniques can determine which solution requires the minimum number of mobile maintenance teams.

Unfortunately, having found such a solution it is not always possible to implement it since consideration must always be given to the existing state of the organisation, e.g. the current investment in plant and buildings, the location of staff and the precedents which have been established regarding their possible transfer. These are constraints which must never be ignored.

The manner in which the Authority's television transmitter network grew and the method of staffing that was used has resulted in most engineers being based at the VHF television stations, and because of this many such sites have been selected as mobile maintenance bases. However, these are not always in the optimum positions for this purpose and there are large remote areas of the country that are properly served only because additional bases have been established.

At present, the whole of the United Kingdom is serviced from 23 mobile maintenance bases as shown in Fig.2. A typical problem will now be discussed to show how the limitations of existing bases come into play. The problem chosen is that of deciding the optimum number of bases and teams required to service the Borders area, between Scotland and England.

Fig.3 shows the probable future pattern of unattended stations in the Borders area, together with the positions of the three existing mobile maintenance bases at Black Hill, Caldbeck and Burnhope. The radial lines indicate a possible allocation of stations to these bases and it will be noted that some stations are remote from all three. If this allocation were to be

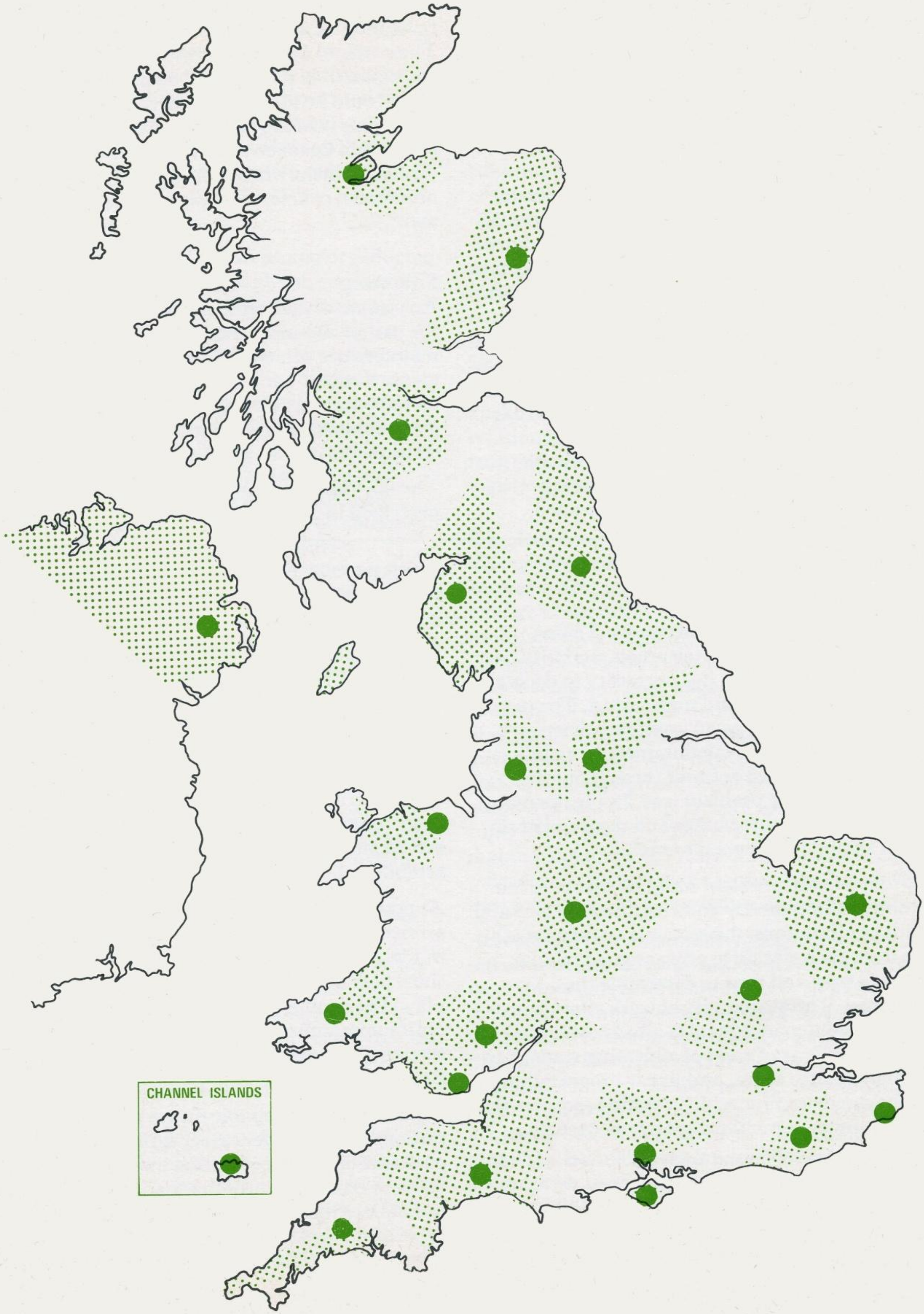
CHANNEL ISLANDS

Fig.2. At present all but 14 of the transmitter installations shown in Fig.1 are operationally unattended and are maintained by a number of mobile maintenance teams operating from 23 bases, one to each of the areas shown tinted in the diagram.
Additional bases will need to be considered as the number of transmitting stations continues to grow.

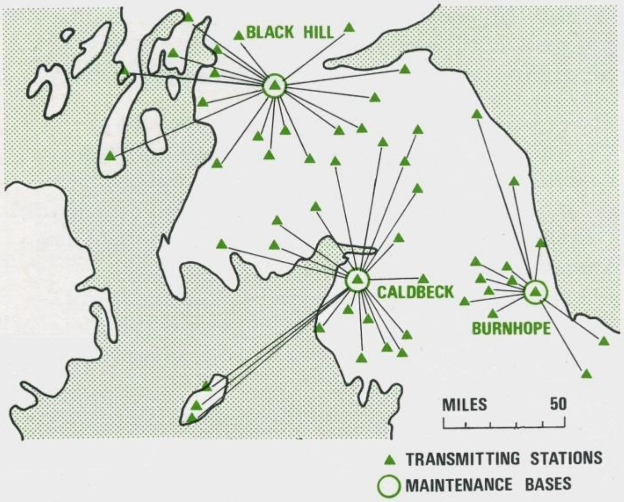

Fig.3. The siting of the existing mobile maintenance bases was largely determined by the siting of the VHF television stations and is therefore not always optimal. A typical problem exists in the Borders area, between Scotland and England, where bases have already been established at the three VHF sites Black Hill, Caldbeck and Burnhope. These are shown in the figure together with the likely pattern of unattended transmitter stations that will ultimately be required to serve the area. It can be seen that however these stations are assigned to the three bases, the mobile maintenance personnel will inevitably spend a lot of time travelling.

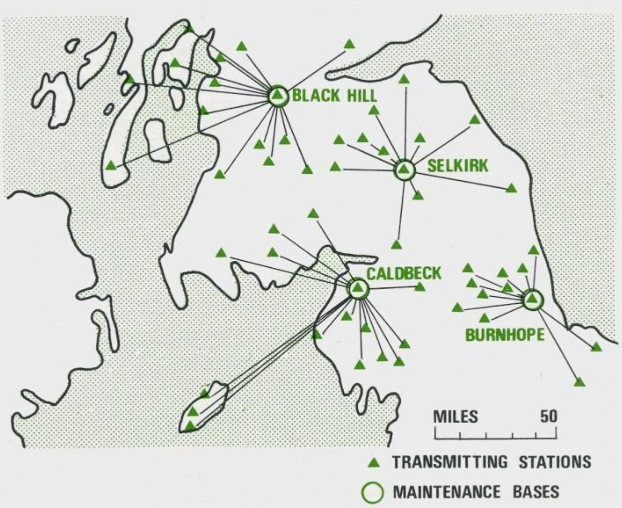

Fig.4. Following on from Fig.3 the effect of introducing a new, fourth, mobile maintenance base at Selkirk has been considered. This not only assists with the logistics but also reduces, from six to five, the number of teams needed to serve the area, see Fig.5.

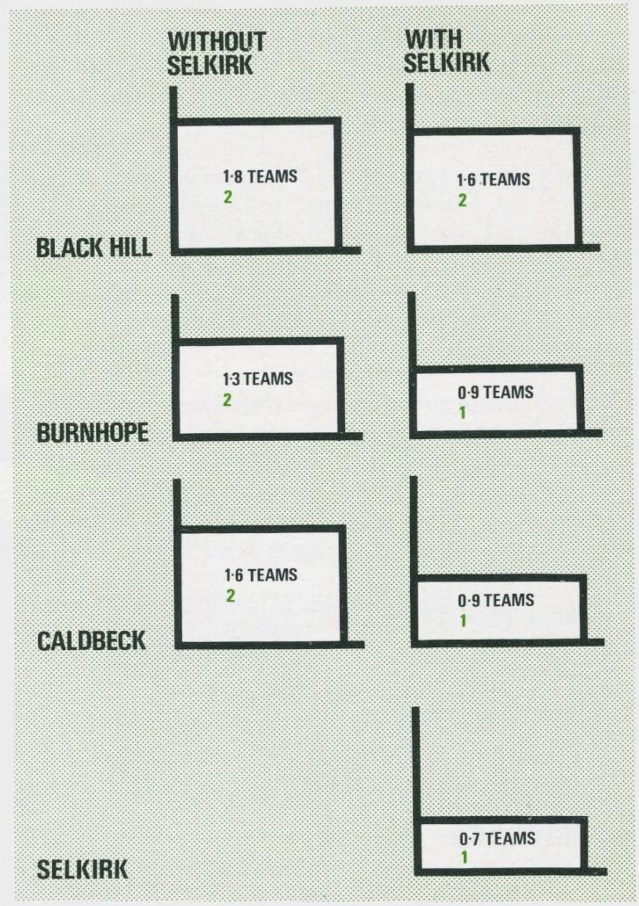

Fig.5. An analysis of the loading on mobile maintenance bases to serve the Border area, between Scotland and England, shows that, by rounding-up the computed number of teams required in each location to the nearest whole number, five teams only would be needed were they to be disposed among four bases, whereas six teams would be necessary if the number of bases were restricted to the original three.

adopted, mobile maintenance teams would waste much of their time travelling. The results on base loading by using just these three bases are shown in Fig.5.

Fig.4 shows an alternative allocation in which the effect of a new base at Selkirk is considered. Fig.5 again shows the result on base loading. Although the loadings are given in fractions of teams it will be clear that only whole numbers of teams can be considered, and therefore each fraction has been rounded-up to the nearest whole number. Fig.5 suggests that by using the three existing bases a total of six teams is required, whereas if a team is located at Selkirk only five teams are required. However, if the Selkirk

solution were adopted, additional cost would arise from the need to provide a new building, stores, staff transfer, etc., and therefore the financial aspect of the proposals would require careful examination before any decision were taken.

It would also be necessary to take staff considerations into account. Selkirk is a small country town and lacks the amenities of those major towns adjacent to the three existing bases. There could therefore be staff resistance, and so it is necessary to decide whether the financial factors outweigh the staff amenity considerations.

Although the problem has been represented as being confined to one area of the country, this is never so. If a base requires only a fraction of a team, an attempt will first be made to trim the load of that base so that it equates to a whole number of teams. This is done by shedding load to, or attracting it from, adjacent bases, but this process could affect many other bases throughout the country. For example, should we decide to trim the Caldbeck load from 1·6 teams to one team by transferring some stations to the Winter Hill base, the result might well be to overload the Winter Hill base and consideration would then have to be given to shedding part of the Winter Hill load to Emley Moor or Lichfield. The problem might even have to be extended further depending upon the loadings of these last two bases.

Problems of this type call for a large amount of clerical effort in manipulating the loadings with changing allocations. To assist in this process a computer program has been developed. The program requires that assumptions be made as to where bases are to be sited and how these stations are to be allocated among them. It then calculates the workloads on these bases and rapidly enables the effects of the various possible allocations to be compared.

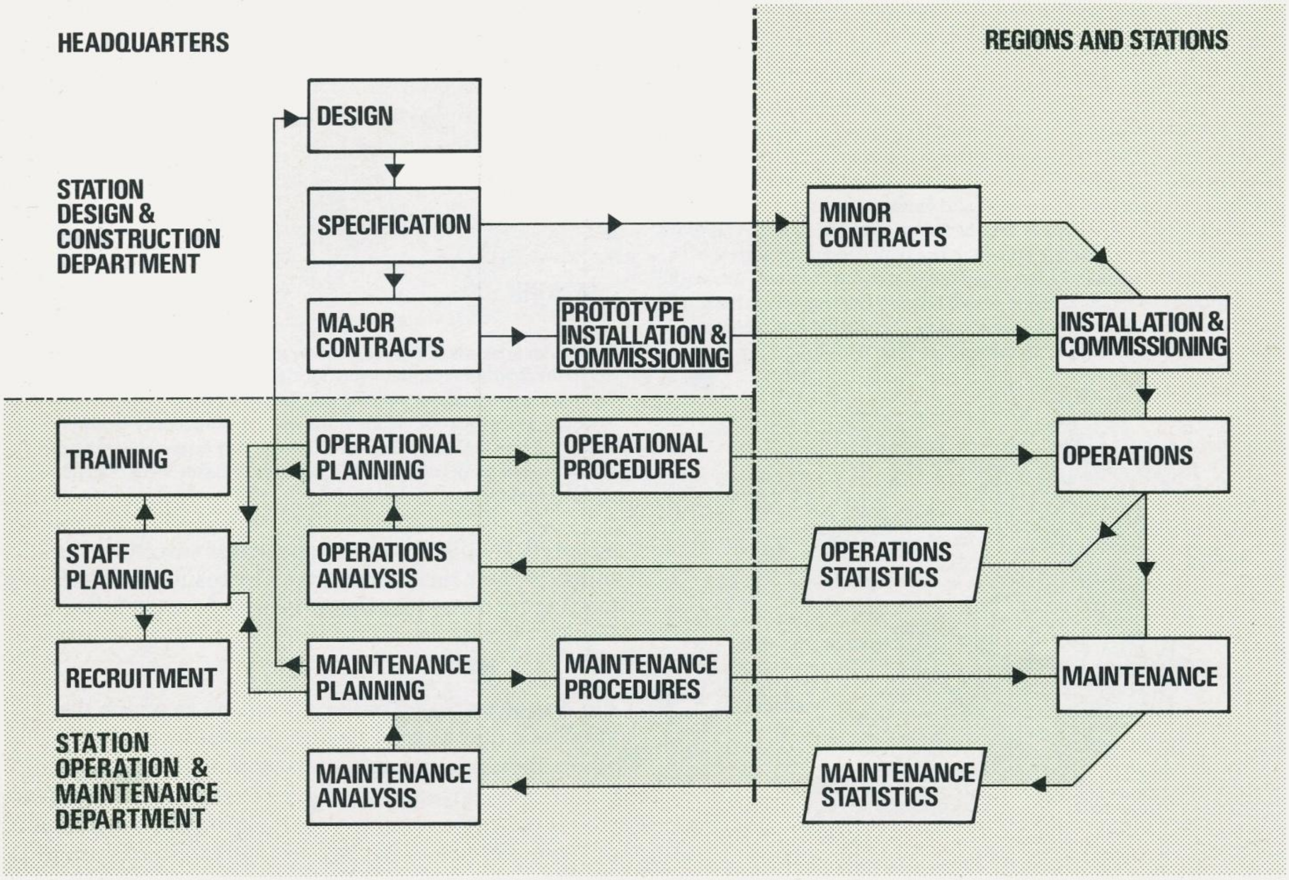

Fig.6. The functional flow of information between the headquarters departments and the operational stations in the regions is not all one way. Two sets of statistics, one dealing with operations and the other with maintenance, are applied as feedback information at the planning stages. In this way experience in the field can influence future thinking, particularly with regard to operational/maintenance procedures and staffing.

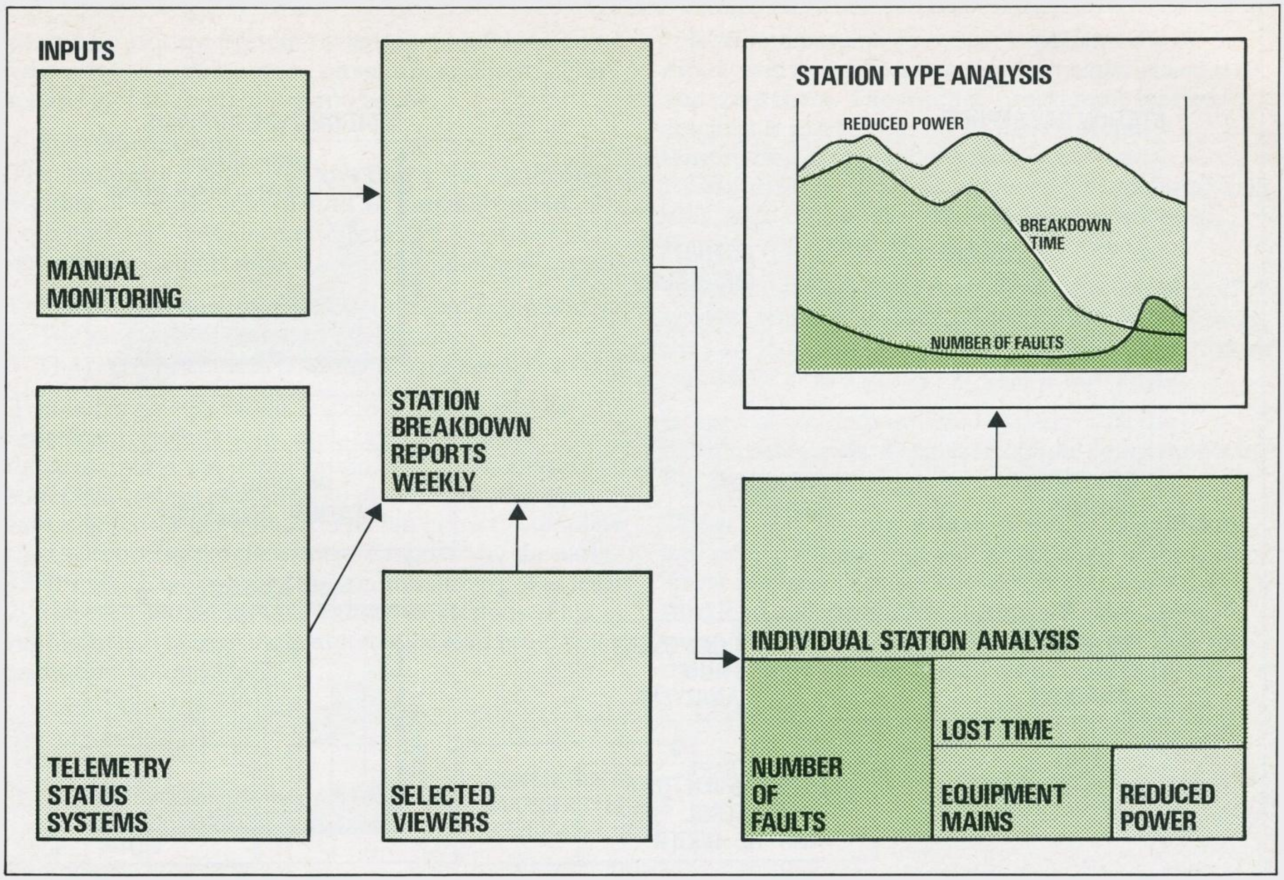

Fig.7. The station breakdown reporting system. Weekly reports are prepared from information derived from the three sources shown. Subsequent analysis then yields the number of faults at a given station, time lost and time spent on reduced power.

2. The Information Gathering System

Any broadcasting organisation must be able to examine its performance and the effort required to maintain it. This then forms the basis of future planning, due account being taken of any changes or corrective action that might be considered necessary.

Fig.6 shows the functional flow of information between the engineering regions, the stations and the headquarters planning departments, and indicates how field experience influences new designs, the operation and maintenance procedures, and the staff planning. The information received from stations is of two types. There is an operational information system which provides breakdown statistics and gives a measure of the overall reliability of the transmitting stations, and a maintenance information system which covers the work undertaken by the mobile maintenance team. The latter contains details as to how the maintenance effort is used and how individual items of equipment are performing.

Fig.7 shows the three sources of information in the operational information system. These comprise the telemetry systems, the monitoring staff and reports from dealers and viewers, etc. The information received from each source is used to compile the station breakdown reports, and from these two types of analysis are made. One shows the reliability of individual stations, their incidence of failure and the amount of reduced power operation, thus enabling comparison of performance between stations of similar type. The second compares the reliability of different station types, and is useful when deciding what equipment, or configurations of equipment, should be purchased in the future.

The maintenance information system based upon the Station Day Reports is shown in Fig.8. One of these reports is completed whenever a mobile maintenance team visits a transmitting station. The report serves the purpose of a station diary and gives details of the

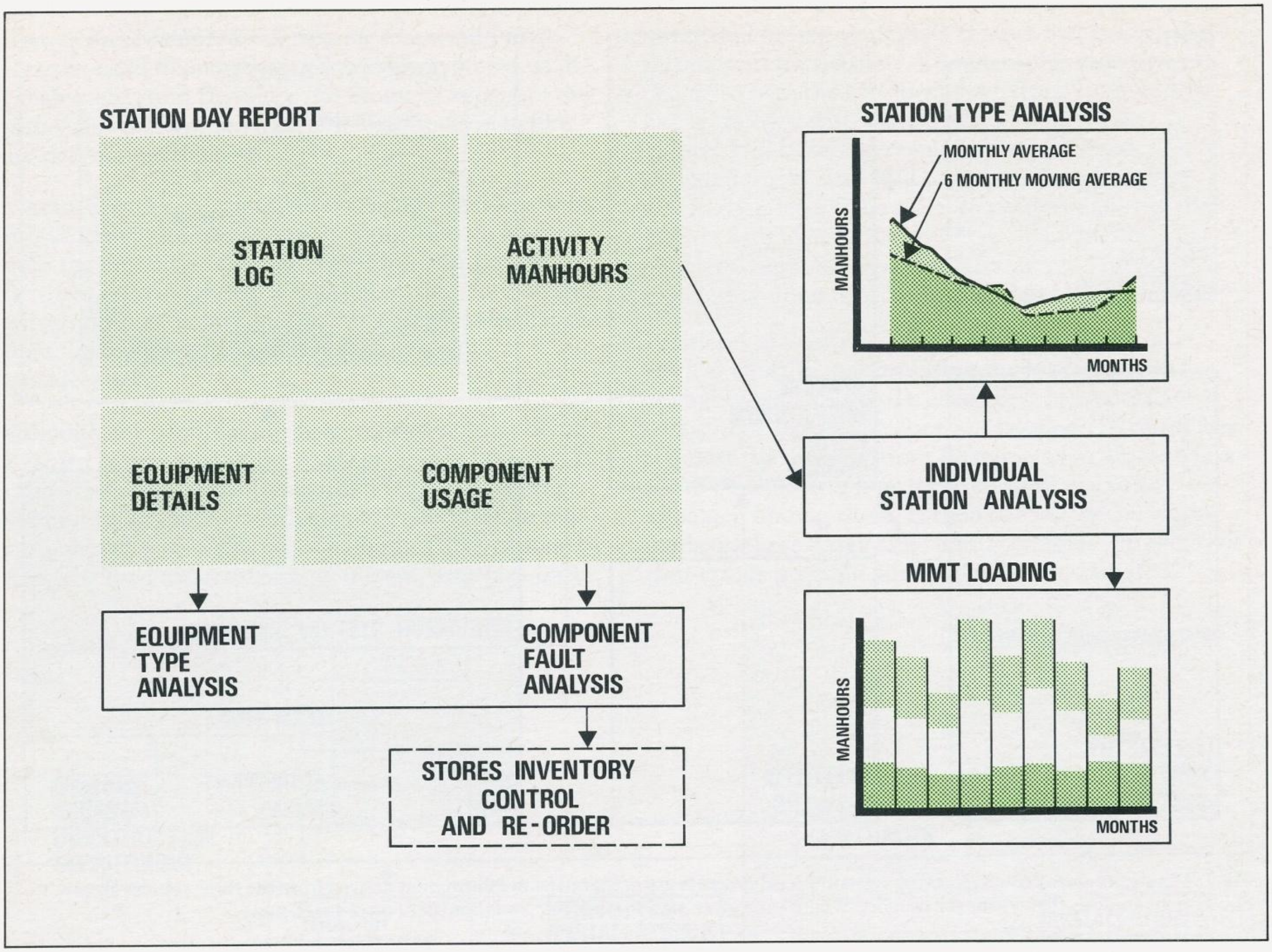

Fig.8. The Station Day Reporting System shown here is in effect a kind of station diary. Reports are completed by visiting mobile maintenance teams providing such details as the number of manhours spent on maintaining different items of equipment and on other activities, and the number and type of components used. Two curves are plotted showing time actually devoted to station maintenance in terms of manhours per month, one being averaged over the previous month, the other averaged over the previous six months. The latter, known as the six-monthly moving average, is usually a rather flatter curve and more indicative of the trend.

time spent on equipment, on activities, and of the components used. From it, three separate analyses are made. The first gives the manhours spent at each station and shows how this effort is divided between the different types of equipment and activities. This enables a comparison of performance to be made between stations of similar type. The second shows the loading of the mobile maintenance teams and gives warning of team overloading; the third shows the average effort demanded by different station types and is useful in isolating equipment design weaknesses and estimating future team loadings. It is proposed that the component analysis will eventually provide the input to a stores inventory control and re-order system.

Fig.9 shows how the analyses from the different sectors of the operations and maintenance information system are brought together to determine what corrective action, if any, is needed, and shows the range of solutions that needs be considered. It will be seen that possible solutions can include equipment modifications, requirements for new test equipments and /or methods, improved documentation systems, additional training, better environmental conditions, etc.

The information system provides the opportunity to identify problems and, in some situations, to anticipate them. Unfortunately, no information system has yet been devised which will solve

problems. But the present system can, and does, show what problems there are to be solved, and it provides a basis for future planning and action.

3. Staff Forecasting

The Authority's need to ensure that it has a sufficient number of trained staff to fulfil all duties required, both now and in the foreseeable future, is vital. The main factors which affect the estimating of staff are:

1. The projected wastage rates of trained engineers
2. The estimated increase in workloads
3 The recruitment and training programme.

Trained engineers vacate station duties by way of retirement, resignations, and transfers to other departments in the organisation, and out of a total staff complement of about 250 the current wastage rate is about 15 per annum. The IBA plans to complete the UHF coverage of the United Kingdom by the early 1980's which will involve the commissioning of at least 200 or even 300 additional transposer stations. This represents an increasing maintenance load requiring additional trained staff.

It is seldom possible to recruit experienced staff direct, and so it is usual to recruit inexperienced staff and train them. The training programme for new entrants is spread over an 18-month period terminating at the end of March each year. Recruitment usually commences in the spring of each year, so that there is a two-year interval between recruitment and completion of the training.

Unfortunately, there is not an unlimited number of suitable trainees available. The IBA's experience over the past four years indicates that to aim for more than eighteen trainees in any one year is unrealistic.

Graphical methods are used to determine the recruitment needs, a typical example being shown in Fig.10.

The graphs show an estimate of the number of duty and relief positions that will be required in the future. These are based upon a knowledge of the present workload and estimates of future workload. One curve, towards the upper part of the figure, indicates the estimated minimum staff requirements for the

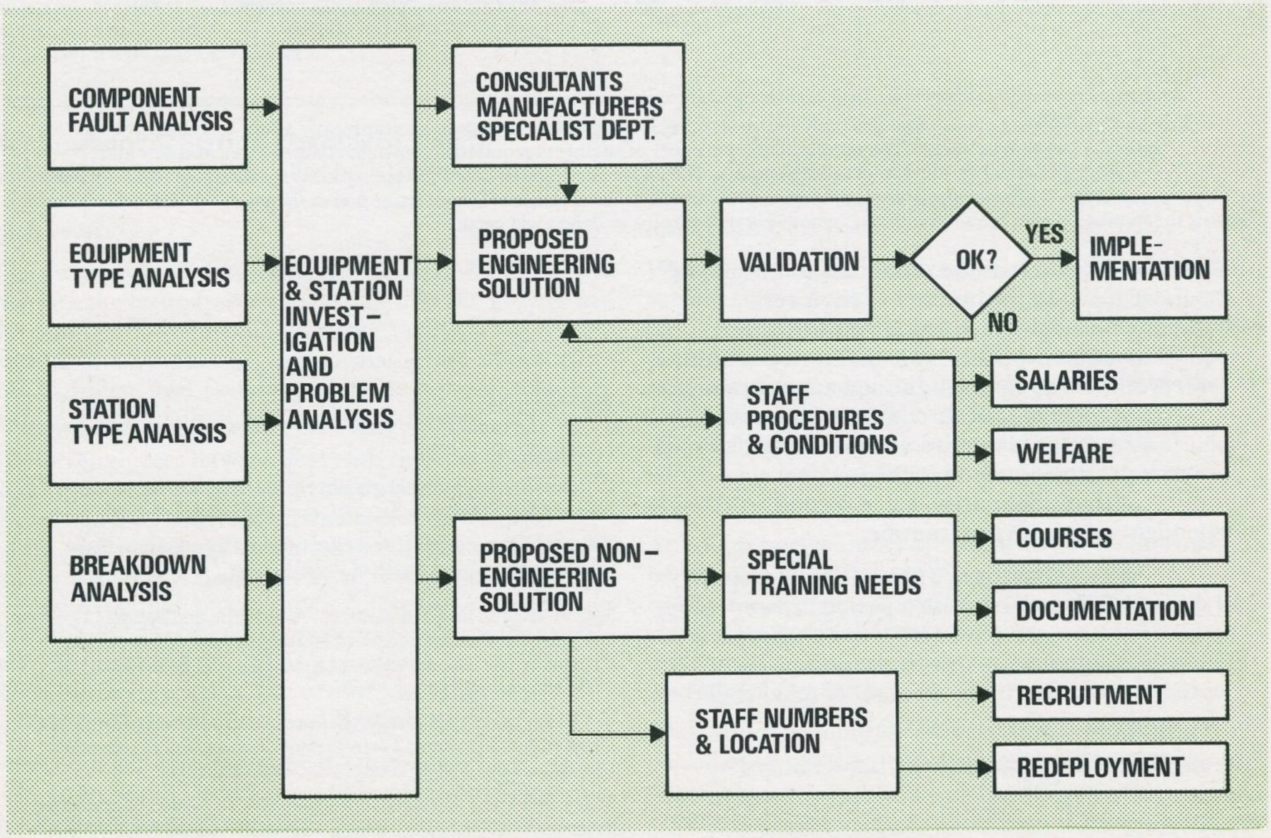

Fig.9. The problem analysis chart shows how statistical information from the four sectors of the operations and maintenance system, when analysed and processed, is taken into account in determining the full range of engineering and non-engineering solutions available.

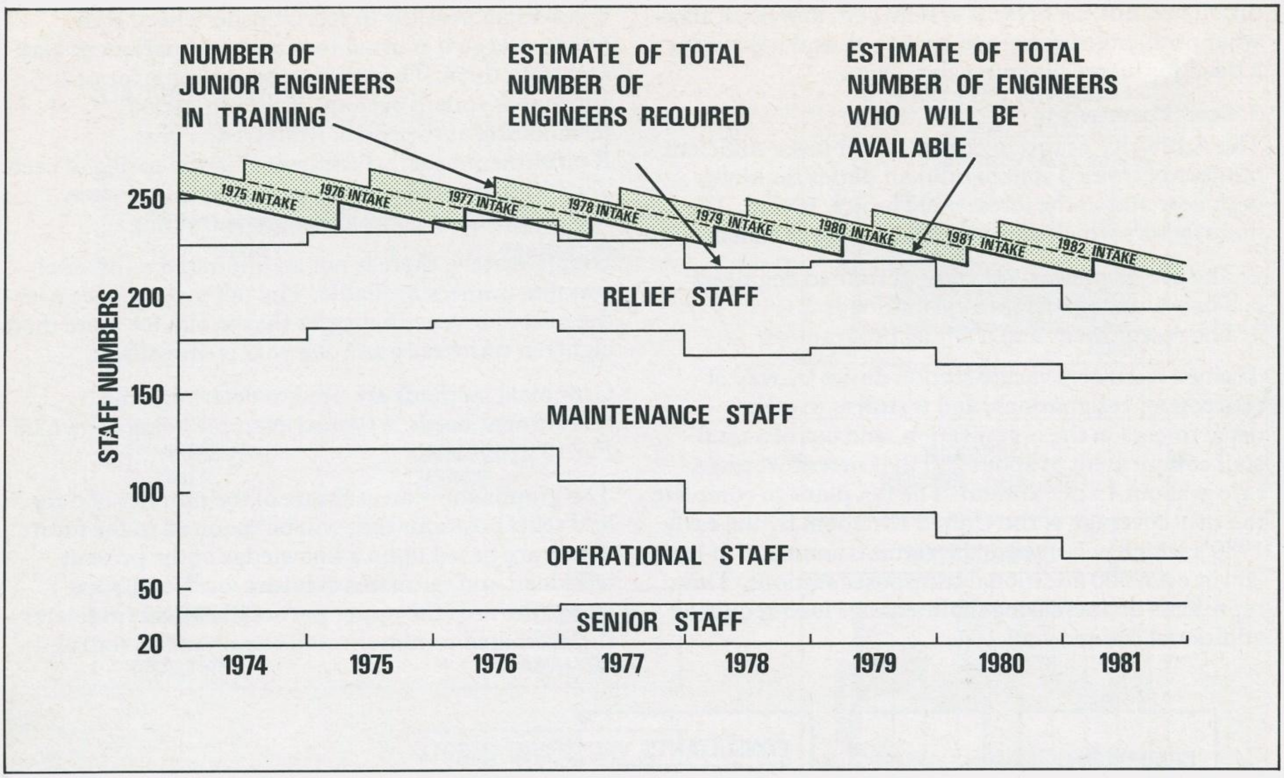

Fig.10. From a knowledge of present and probably future workloads it is possible to determine graphically a staff recruitment target for each of the several years that lie ahead. The minimum total number of engineers required is shown as comprising operations and maintenance staff, together with a number of relief positions. The upper curve shows how this total number is calculated. The sawtooth shaped line shows the number of engineers estimated to be available at any one time. The extent to which the sawtooth line exceeds the line showing the number of staff required indicates whether a staff surplus or deficit will occur.

period 1974–81, whereas the rather sawtooth shaped curve above it shows the number of engineers estimated to be available at any time during that period. It assumes a wastage rate of fifteen per annum and a recruitment programme aimed at maintaining a reasonable surplus of staff throughout most of this period. This surplus is required to ensure that a rapid response is possible in the event of any new commitment that might arise, e.g. a second independent television programme.

The graph shows that there will be a small drop in staff during 1976 and, because a period of two years is necessary for any corrective action to be taken, it is possible to accommodate this shortage only by accepting a reduction in the number of relief staff that will be available during that period.

The graph is effective in showing how changes in workload and in staff wastage and recruitment rates are interrelated. It provides a simple method of deciding future recruitment rates in response to changes in the rates of wastage and/or workload.

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These last three references detail some of the techniques used in the automatic and remote control systems of the IBA.

PAT STANLEY, CENG, MIEE, on leaving Loughborough College, joined the BBC and for most of the eight years that followed was employed on several of the first high-power television transmitters to be commissioned. He then joined the Authority in 1955 as Assistant Superintendent Engineer, Operations and Maintenance Department. Since then he has become Head of Operations Section of the Station Operations and Maintenance Department, and includes in his duties the responsibility for the recruitment and training of engineering staff within that department.

Engineering Staff Recruitment and Training

by P S Stanley

Synopsis
This article describes the methods of recruitment and training of station engineering staff required for operating and maintaining the IBA transmitter network.

Because it is seldom possible to recruit experienced staff to cover wastage or to fill new posts arising as a result of the extension of the transmitter network, it is usual practice to recruit an annual intake of trainees and to provide them with an 18-month period of training.

The methods of selection and the details of the training syllabus are described.

To enable experienced engineers to service the more modern forms of equipment, specialised courses are provided at manufacturers' works and the Authority's Training Unit in South Devon.

Recruitment of Station Engineering Staff

The previous article describes how the recruitment target for new station engineering staff is determined each year.

The factors which determine the target number in any year are the estimated staff wastage and the growth in the number of mobile maintenance teams. The number in any one year will normally vary between ten and eighteen, and as indicated in the previous article it is unrealistic to aim for more than eighteen.

Station engineers have to deal with the operation and maintenance of a wide range of complex equipment featuring many different technologies; they are additionally expected to work in small groups of two or more and are required to serve in any part of the United Kingdom. Great care is, therefore, needed in selecting candidates for these posts to ensure that not only do they have the appropriate level of background education, but are also suitable in terms of their personal qualities and circumstances.

Minimum academic qualifications required are Higher National Certificate, Higher National Diploma in Electrical Engineering or City and Guilds Full Technological Certificate in appropriate subjects. It is also desirable for candidates to have had some industrial experience but some trainees are taken direct from technical colleges, polytechnics and universities.

When selecting candidates for the rather restricted social environment of station life, attention must be paid to their general attitudes and motivation, and to their personal circumstances. This is especially necessary when appointing graduates, some of whom may become frustrated with the limited opportunities for any form of research or development activity which sometimes appears high on their list of career objectives.

Although no age limits are set, trainees are normally between 21 and 30 years of age. Ideally, they already hold a driving licence and have some driving experience because eventually they are required to drive mobile maintenance vehicles, but driving lessons are given if required.

The training course for new recruits extends over a period of 18 months, and during 33 weeks of this period they are required to attend Plymouth Polytechnic for formal study. These Plymouth courses take place at the rate of only one per year, and so the recruitment campaign can produce only a single

annual intake. Advertising for these training posts appears in selected daily newspapers, weekly trade journals and other publications as appropriate. Additionally, a more direct approach to potential applicants has recently been made by visiting certain colleges and polytechnics where relevant courses are being conducted.

Usually, there is a response from between 500 and 800 applicants who are then sent full details of the job and the organisation. They are all invited to complete an application form but usually only about 150 actually do so, and of these only about half are considered suitable for interview. It is, therefore, usual to interview about 60 or 70 people each year, see Fig.1.

The interviews are conducted at an operational transmitting station so that the candidates can be given the opportunity of seeing a typical working environment, and to obtain some idea of the duties involved. The interview programme for each candidate lasts approximately two hours and is in four distinct parts. The first comprises a short written test which enables the candidate's knowledge of fundamental concepts in electrical and electronic engineering to be evaluated. The second is in the nature of a conducted tour of the station, during which the candidate is given the opportunity to ask the staff questions relating to any aspect of the equipment and/or conditions of service. In this way it is possible to assess the candidate's understanding of basic transmitter systems and general level of interest.

The third part of the programme is a formal interview on engineering subjects. During this the candidate is questioned on the answers to the test paper, and other questions are put as appropriate.

Finally, there is a further interview with a member of the Personnel Department whose main interest is establishing the applicant's suitability as a Station Engineer in terms of temperament, attitude, physique and general health, as well as personal circumstances.

As a result of this selection process, 20 to 25 candidates may be offered appointments; but not all these offers are accepted and experience has shown

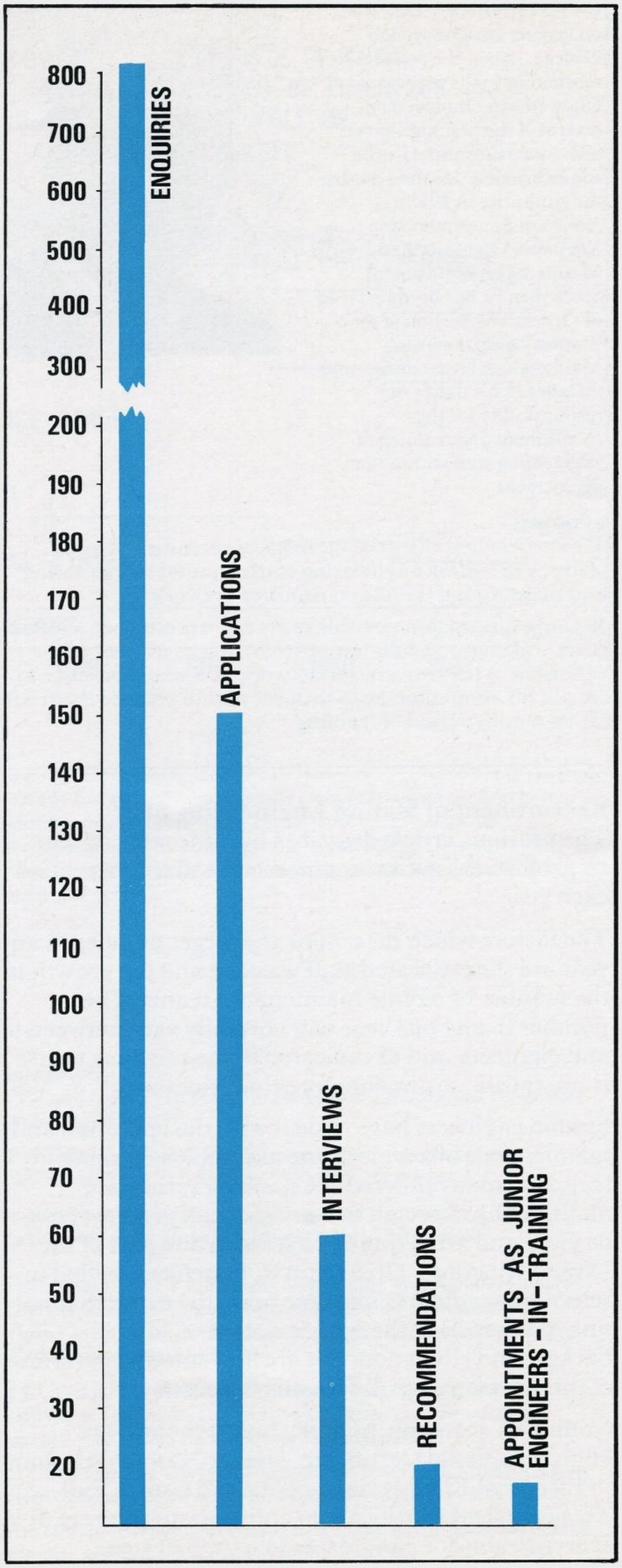


Fig.1. Each year the advertising of trainee vacancies attracts up to 800 enquiries. Information concerning training, together with an application form, is sent to each enquirer. The forms are returned by about 150 persons only, and of these 60 are usually worthy of an interview. Following the interviews appointments are offered to about 20 candidates of whom approximately 15 eventually join the service of the Authority.

that it is unusual to end up with more than 18 trainees. Offers of employment are always subject to satisfactory references, and a full medical report including a colour vision test.

The method of selection described is deliberately thorough, but it is considered fully justified both from the employer's point of view, and that of the candidate. Apart from the financial commitment which a candidate's training programme represents on the part of the Authority, each candidate would be committed to an 18-month period of training without any guarantee of subsequent employment unless the whole programme is completed with the required degree of success. The method is orientated, therefore, towards selecting those candidates whose potential in terms of satisfactorily completing the course is considered good.

The 18-month training programme consists of both academic and practical training periods. During half the time, the trainees attend Plymouth Polytechnic for a course in Advanced Television Engineering, Figs.2 and 3, and the remaining nine months are spent undergoing practical training at a transmitting station. These two parts of the training are interleaved in the manner of a sandwich course, see Fig.4. This also shows that the Plymouth course is itself in three parts, the first dealing with electronics and pulse circuit techniques, the second with the generation of the composite video waveform and the manipulation and processing of sound and vision signals up to the transmitters, and the third with transmitter, aerial and feeder design.

Fig.2. Junior Engineers-in-Training spend a total of 33 weeks on a course in Advanced Television Engineering at the Hoe Centre of the Plymouth Polytechnic in Devon, and are accommodated in a nearby hotel in the vicinity of Plymouth Hoe.

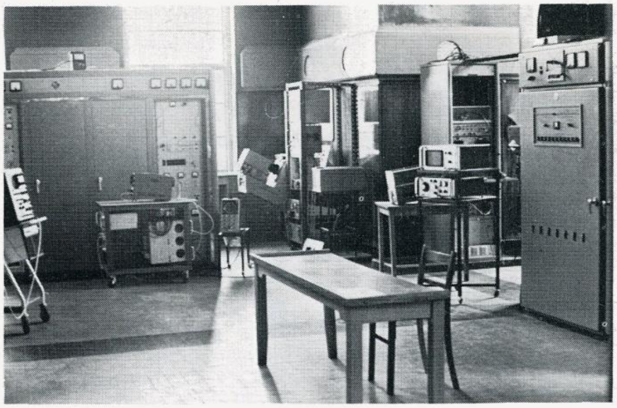


Fig.3. Transmitting equipment, similar to that in service, has been provided at the Hoe Centre by the Authority especially for use by trainees while receiving their instruction.

Any student who is successful in each of the three terminal examinations can earn endorsements to a Higher National Certificate. Furthermore, any student who gains an average pass mark of 50 per cent, calculated from the results of any two terminal examinations, is awarded a Plymouth Polytechnic Diploma. The course is a recognised educational course and, as such, is open to any organisation or private student.

The practical, on-station part of the training programme is controlled from the Authority's Engineering Training Unit based in South Devon and is supplemented by induction and workshop-practice courses at the Training Unit. Each student is provided with a programme of work designed to directing attention to the essential components of a broadcasting system, and any special problems that might exist at the transmitting station where the student is based. The training is administered by correspondence from the Training Unit and the practical work is supervised by the local station senior engineering staff.

It has been estimated that the current cost of training a student in the manner described, including course fees, accommodation expenses, travelling and salary during the training period, is about £6,000. On average more than 90 per cent of trainees obtain the necessary level of performance and are appointed to the station engineering staff.

Applications for direct entry to the station engineering staff are invited from time to time. In this case, applicants are required to have the same academic qualifications as are trainees, but in addition they should have had substantial experience with television systems and particularly of television

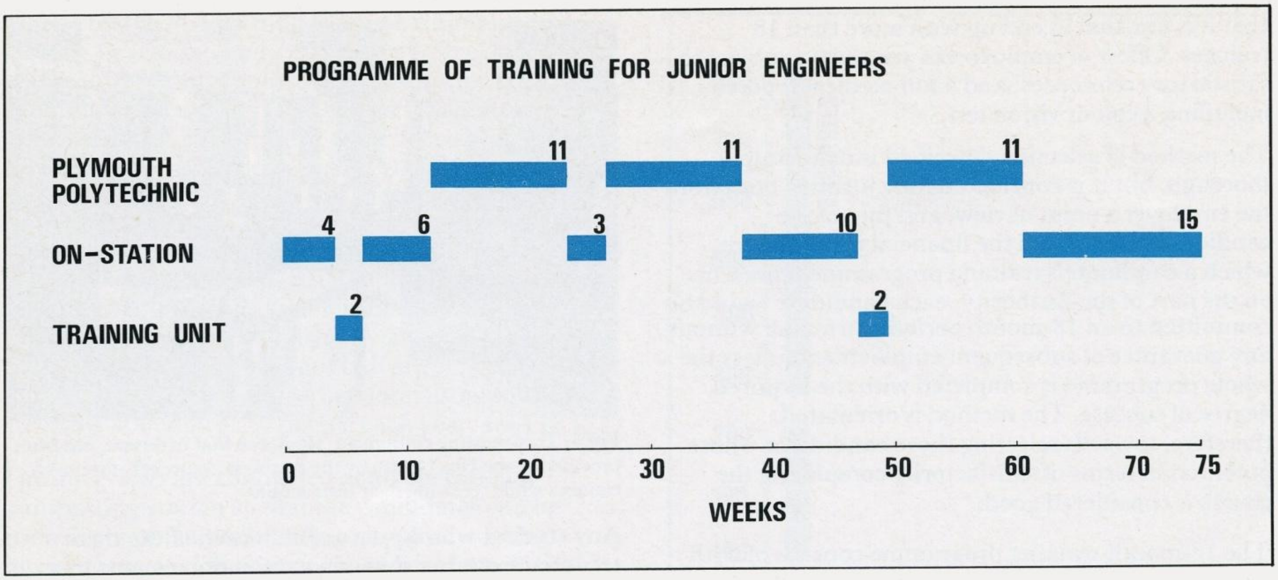


Fig.4. The trainees, in addition to receiving instruction at the Plymouth Polytechnic, are trained on-the-job at the transmitting stations to which they have been appointed for the duration of their training programme. They also attend short courses on workshop practice and equipment maintenance at the Authority's Engineering Training Unit in Devon. The pattern of the complete course is shown here.

transmitters operating at VHF and UHF. The number of applicants is very small, amounting to one or two a year.

The IBA Engineering Training Unit

Although some manufacturers are able to provide courses of training in the design and operation of their equipment, such courses are few in number and are not usually available for equipment which has been in service for some considerable time. Whether manufacturers' courses are available or not, a broadcasting organisation has a need to provide practical training for its staff for equipment already in service, and also for any new items of equipment being introduced into service.

In addition to providing courses on equipment design, there is also a need to instruct staff on the use of measuring and test equipment in order that a uniform approach to the methods of testing and measurement be achieved throughout the organisation.

To meet these needs a small Training Unit has been established in South Devon. The unit currently has a staff of three instructors with appropriate clerical support, and it is able to provide training on specialised items of transmitter equipment and measurement techniques. It is equipped with lecture rooms and equipment laboratories, see Fig.5, and is currently capable of running simultaneously two course programmes each of which may be attended by a maximum of ten students. The duration of such courses can vary from one to three weeks and their syllabuses are designed to meet the needs of transmitter maintenance engineers.

Most members of the station engineering staff will attend all those courses relevant to their work. However, because the Training Unit is small, some considerable time can elapse before all engineers requiring instruction can be accommodated.

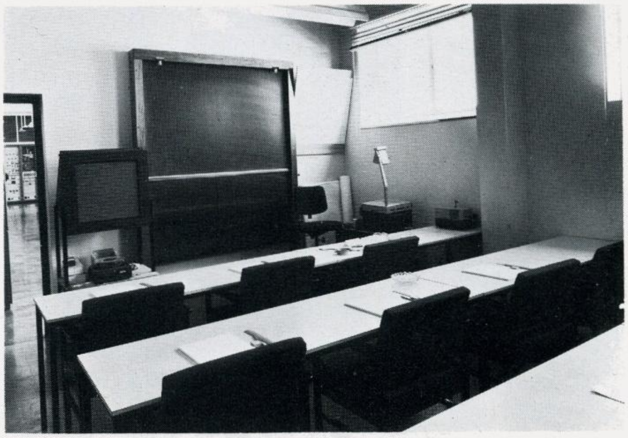


Fig.5. One of the lecture rooms and an associated equipment laboratory in the Engineering Training Unit. The lecture room is equipped with a roller blackboard, overhead projector and slide projector.

In an attempt to overcome this problem, and to supplement the training resources at the Unit, a series of correspondence courses supported by video and audio taped material is being prepared. These will give instruction on a range of technical equipment, and will be distributed to the stations. A disadvantage is that these courses do require considerable time for their preparation, and this factor is somewhat limiting.

Induction courses for the benefit of new staff are also held at the Training Unit. These are designed to promote an awareness of the functions and duties of the Authority, an understanding of the work of the Engineering Division and how this work is divided between the various departments, and an appreciation of the basic elements of television broadcast engineering.

External Training Courses

Where appropriate training courses are available from manufacturers or training institutions, they are attended by members of the station engineering staff. Amongst these is a 3-week course provided by the Marconi College on the design and maintenance of one type of UHF transmitter used by the Authority. This transmitter employs IF modulation techniques and makes considerable use of strip-line technology and logic circuits. The college also runs a course on the logic systems employed in the telemetry equipment used in the Authority's network of unattended transmitters, and provides courses on the repair of printed circuit boards.

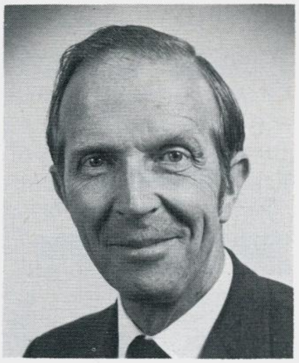
Other courses are provided by professional institutions, but these are more orientated towards the theoretical aspects of equipment and systems design. One such course at the Leeds Polytechnic on 'Digital electronics for television engineers' is attended by station staff and provides a valuable introduction to a subject which is assuming increasing importance.

Specialist courses are attended by head office and regional engineering staff as appropriate to their work. Subjects covered include reliability engineering, development documentation systems, and more general courses on safety at work.

Staff are also encouraged to pursue other forms of training in their own time, and are fully supported in doing so. This can include attendance at local part-time or evening courses where available, or by participation in correspondence courses. Suitable courses are operated by a number of Correspondence Schools and by the Institution of Electrical Engineers.

Engineering training, if it is to be effective, needs to be closely related to the dynamic situation which is found in a progressive broadcasting environment. The training needs of technical staff throughout the Engineering Division are therefore regularly reviewed in the light of the constantly changing requirements.

DESMOND LAVERS, MBE, CENG, MIEE, joined the Authority in 1958 after leaving the Marconi Company Limited, where for seven years he had been responsible for installing high-power television transmitters, both in this country and abroad. In 1965 he was appointed Senior Engineer Maintenance and in April 1967 took up his present appointment as Head of Maintenance Section.



ALEC MORECRAFT spent eight years in the RAF during which time he was mainly engaged in maintaining air-borne radar and radio equipment. Upon joining the Authority in 1960 he served at a number of transmitting stations, but in 1963 he was transferred to Headquarters staff and has since specialised in planning the maintenance of unmanned relay stations and the production of maintenance aids. He lives near Romsey, in Hampshire, with his wife and three children, and his hobbies include photography and wine making.

Some Aspects of Maintenance

by J D V Lavers and A C Morecraft

Synopsis
Modern solid-state equipment is both complex and reliable. For the maintenance engineer, however, these two qualities, complexity and reliability, present considerable problems in that they conspire to reduce the amount of time he spends servicing any given piece of equipment and hence his familiarity with it. Next to a sound basic training, adequate refresher courses and opportunities to gain experience, the maintenance engineer requires clear and concise documentation if equipment outage time is to be kept to a minimum and if he is to gain satisfaction, rather than frustration, from his work. A method of diagnostic documentation, known as Functionally Identified Maintenance Systems (FIMS) has been introduced by the Maintenance Section of the Station Operations and Maintenance Department and is making a valuable contribution towards solving this problem.

Even today, with the advanced state of technology, many components used in broadcast transmitters have a finite life and a predictable wear-out pattern. Preventive maintenance acknowledges this fact and attempts to limit equipment 'down-time' by anticipating failure. Planned maintenance, on the other hand, by the introduction of periodic checks, is aimed at ensuring that equipment operates correctly.

With an ever-increasing number of unmanned stations to maintain, it is considered important that essential work be carried out on a regular basis. This is arranged by the Preventive Maintenance Working Party who study the subject in detail and devise a method of regular checking using carefully formulated Preventive Maintenance Schedules.

MAINTENANCE DOCUMENTATION

In the first phase of the Authority's growth, which involved the construction of its VHF network, the vast majority of stations were manned, and so the resident maintenance staff lived almost continuously with the equipment and became extremely familiar with it.

Equipment familiarity is directly related to its reliability. Comparatively speaking, the generation of 405-line VHF equipment that was installed in the 1950s and 1960s is not particularly reliable because it uses thermionic valves and conventional components, and unlike modern solid-state equipment, it has a meantime between failures in the order of weeks, rather than months. The maintenance engineer was thus involved with corrective and preventive maintenance of a very limited range of equipment. In consequence, his need for documentation was minimal and providing he had circuit diagrams, component layouts and schedules, he could locate and rectify most faults reasonably quickly. With the later introduction of the Authority's network of large numbers of UHF stations the situation changed radically. This UHF network was planned from the beginning on the basis that it would be unattended; and it uses equipment which is considerably more complex, more diverse and (to make things worse from the point of view of getting to know it) more reliable than its 405-line counterpart. For each of these reasons

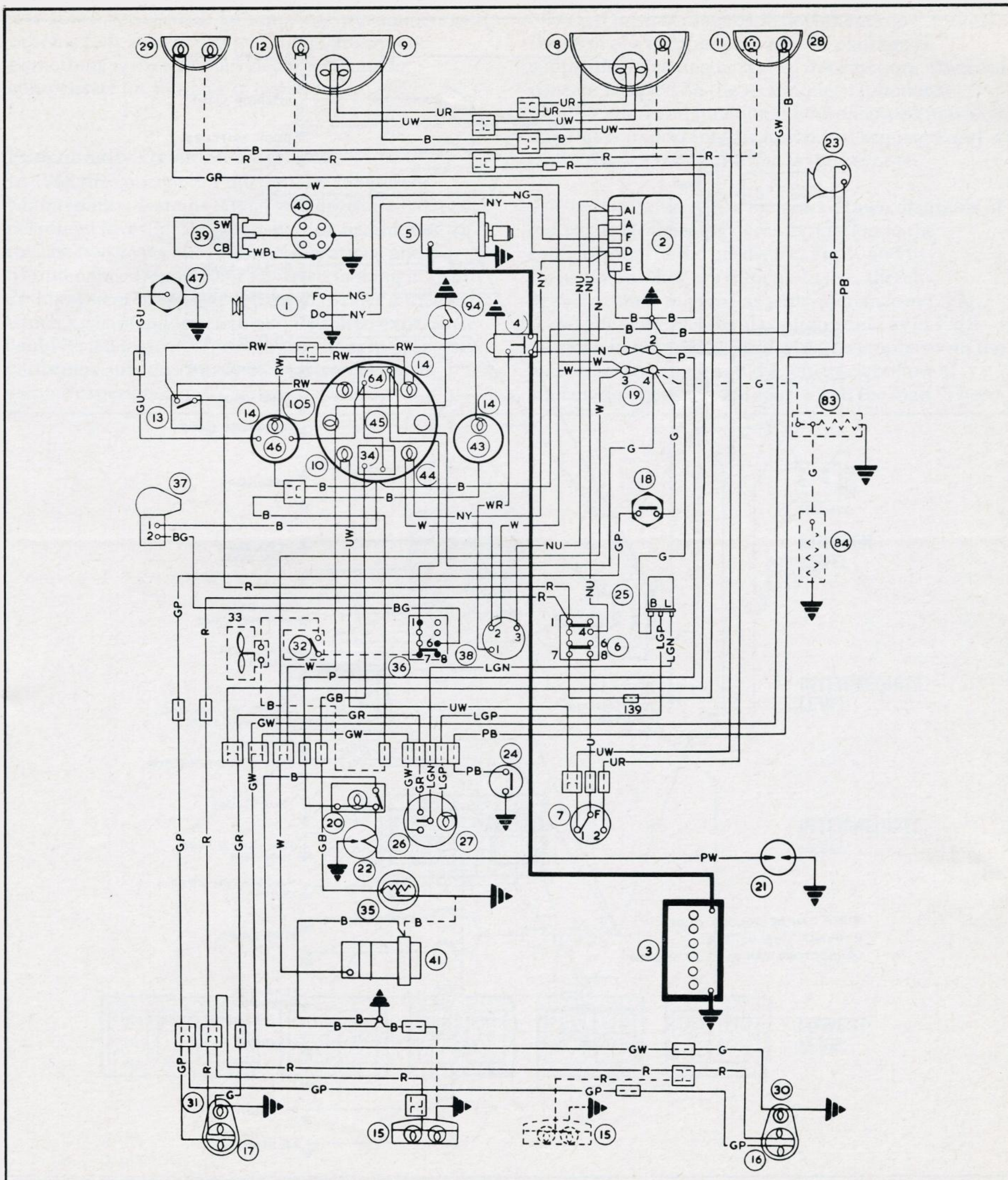


Fig.1. A typical car wiring diagram with which most people are familiar. It emphasises spatial relationships in that the layout of components follows, to some extent, the physical arrangement in the car. This results in the diagram having a large number of wiring cross-overs and parallel runs, and a lack of any 'direction' or functional flow. In consequence it appears cluttered and is difficult to follow.

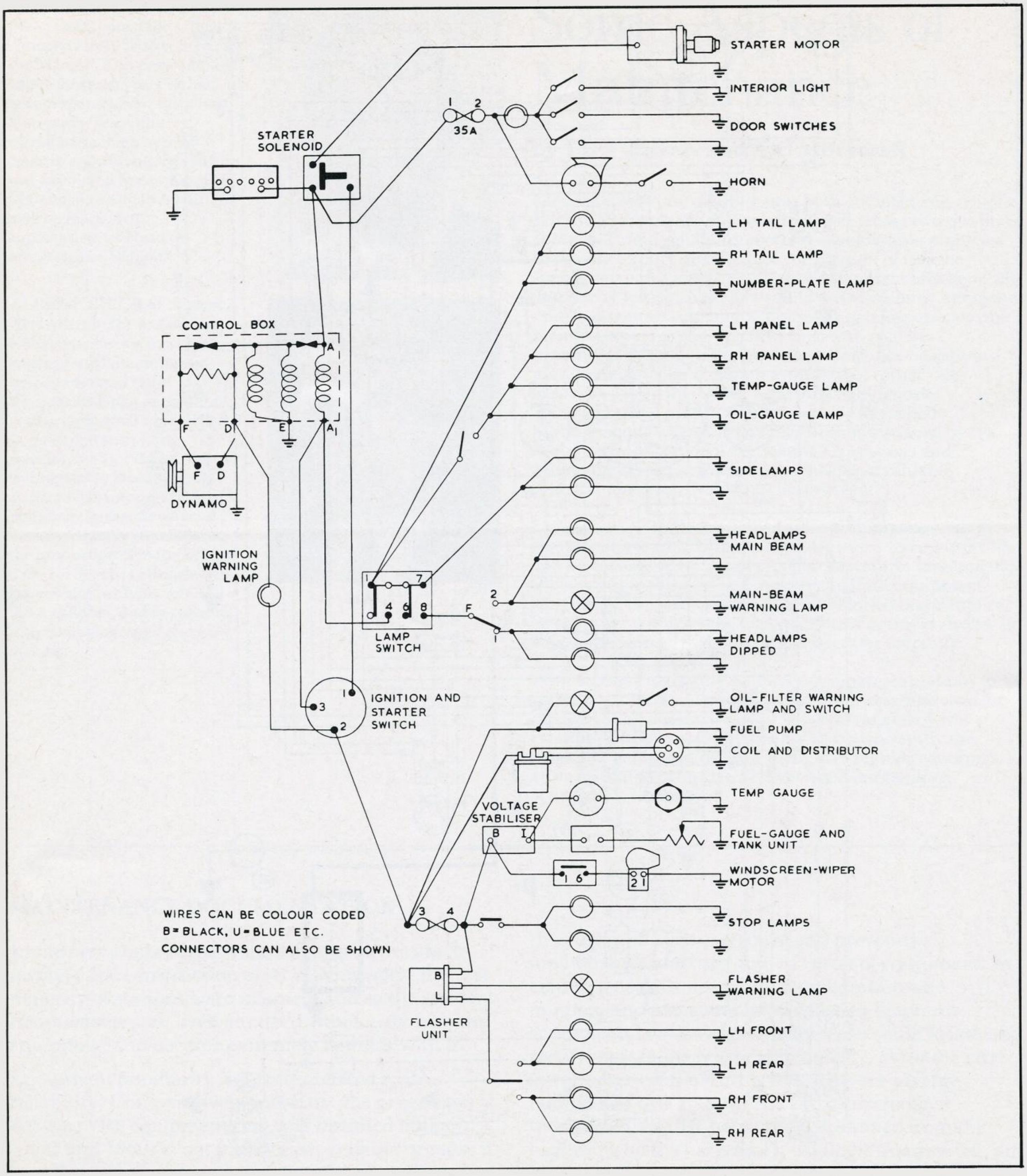


Fig.2. A functional car wiring diagram. This is the same circuit as that shown in Fig.1 but here the two main sources of information or, in this case, electrical power have been placed on the left and the outputs have been arranged one above the other on the right. Emphasis is thereby placed on the left-to-right flow of information and provides a method of presentation which allows one readily to see the function of each component in relation to the circuit as a whole. *Crown Copyright, reproduced with the permission of Her Majesty's Stationery Office.*

it is now more difficult for maintenance engineers to become fully conversant with their equipment. Something is therefore needed to be done to compensate for this lack of experience.

Functionally Orientated Systems
In 1968 the concept of Functionally Identified Maintenance Systems (FIMS) was developed by naval personnel investigating fault-finding techniques. In the last two years, the Station Operations and Maintenance Department has been looking in depth at this system because it appeared to offer a means by which a maintenance engineer of limited experience could be led logically through the thought processes performed subconsciously by a person of much greater experience.

FIMS is a form of diagnostic documentation. It takes the form of a complete diagnostic package to supplement existing technical information. The entire concept is based on the technique of functional identification and functional flow diagrams in which, and this is important, the functional sequence and not the hardware configuration, is the keynote.

The motor industry has for years drawn diagrams of motor car electrical systems in relation to the configuration of the hardware, Fig.1, and in consequence they are difficult to use, thereby defeating their purpose as a maintenance aid. Fig.2 shows the same electrical configuration as in Fig.1 redrawn in functional form with the emphasis on the functional sequence and the left-to-right flow of information between the source and the load. There

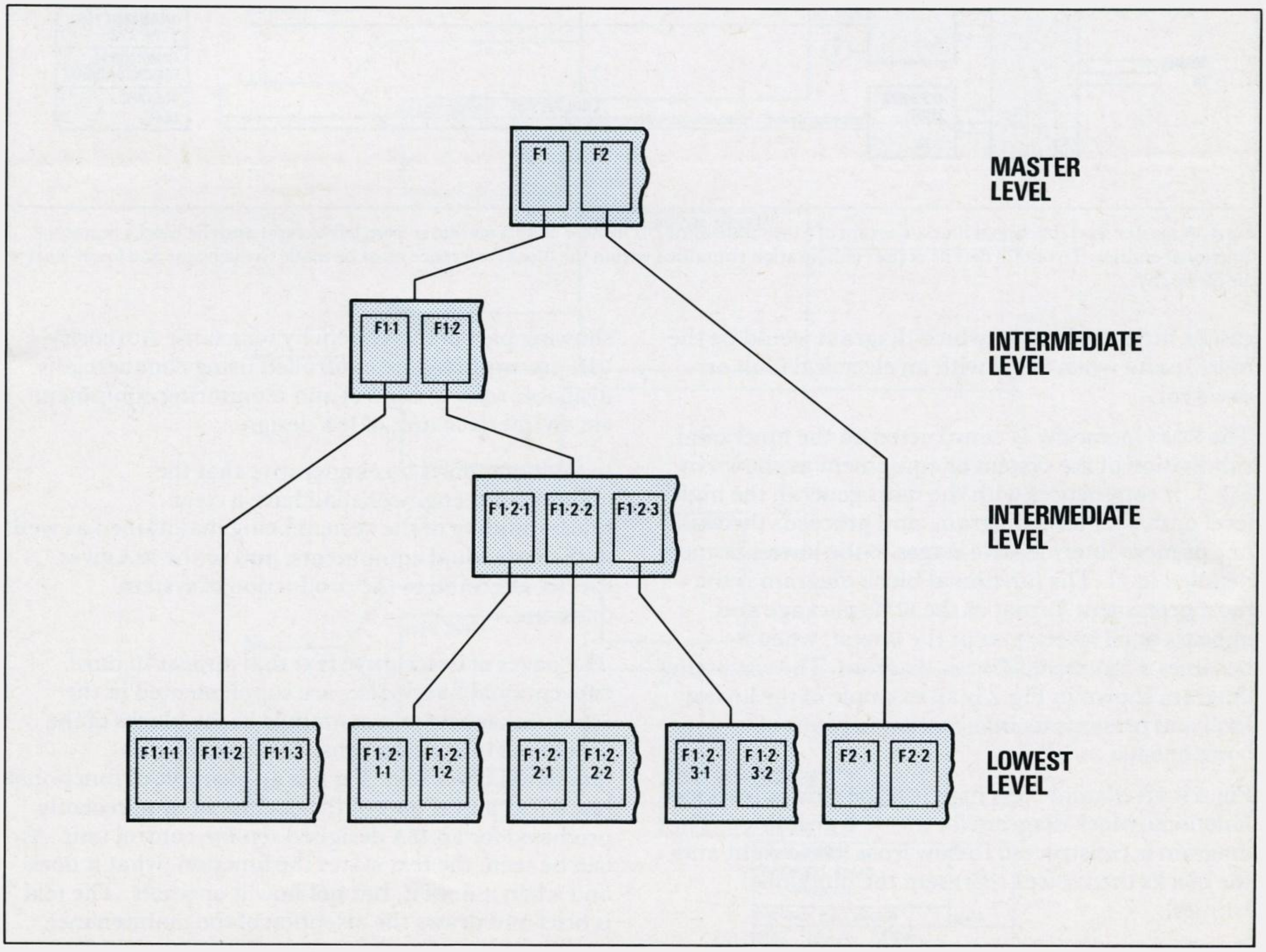


Fig.3. The essential ingredients of a FIMS (Functionally Identified Maintenance System) are a hierarchical subdivision into a number of levels and a functional flow of information from the most general or master level, through the various intermediate levels to the lowest or most detailed level. The usual format for information in a FIMS package is the functional block diagram. This appears at all levels except the lowest where the form is that of a functional circuit diagram.

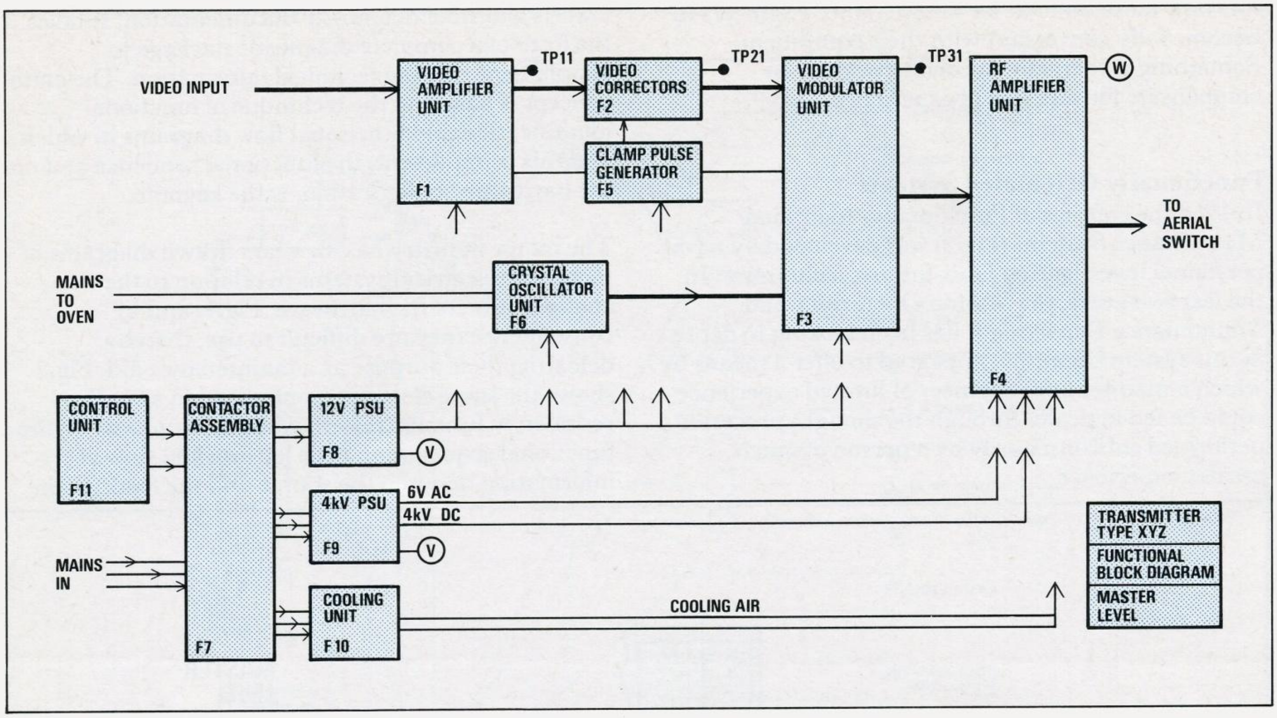


Fig.4. A master level functional block diagram of a UHF transmitter. The flow of information is from left to right and the blocks represent functional entities. To obtain details of the configuration contained within the blocks reference must be made to diagrams at a lower level in the hierarchy.

can be little doubt as to which diagram would be the more useful when faced with an electrical fault on one's car.

The FIMS hierarchy is constructed on the functional subdivision of the system or equipment as shown in Fig.3. It commences with the most general, the high level or master level diagram, and proceeds through one or more intermediate stages to the lowest or most detailed level. The functional block diagram is the most prominent format in the FIMS package and appears at all levels, except the lowest, when it becomes a functional circuit diagram. The car wiring diagram shown in Fig.2 is an example of the lowest level and presents its information in terms of components.

Fig.4 is an example of a high level or master level functional block diagram for a UHF transmitter. The diagram is constructed to flow from left to right and the blocks themselves represent the functional entities.

To relate functional boundaries to hardware boundaries colour tones can be introduced, light blue for functions and light grey for hardware content. Fig.5 is an example of a systems block diagram showing part of the system by which the Authority's UHF transmitters are controlled using commercially available remote control and monitoring equipment via an interface unit of IBA design.

In fault diagnosis it is imperative that the maintenance engineer shall have a clear understanding of the system being maintained as well as the individual equipments, and so the IBA gives special attention to the production of system diagrams.

The pages of descriptive text that appear in most conventional handbooks are supplemented in the FIMS package by text contained in the blocks of the functional block diagrams. This is known as functional block text. Fig.6 is an example of functional block text and is part of the documentation recently produced for an IBA designed remote control unit. As can be seen, the text states the function, what it does and when it does it, but not how it operates. The text is brief and draws the attention of the maintenance engineer to the functions performed. Fig.6 overlays Fig.7 which is the functional circuit diagram, and in this way the maintenance engineer is led from one drawing to the next and so is presented with the

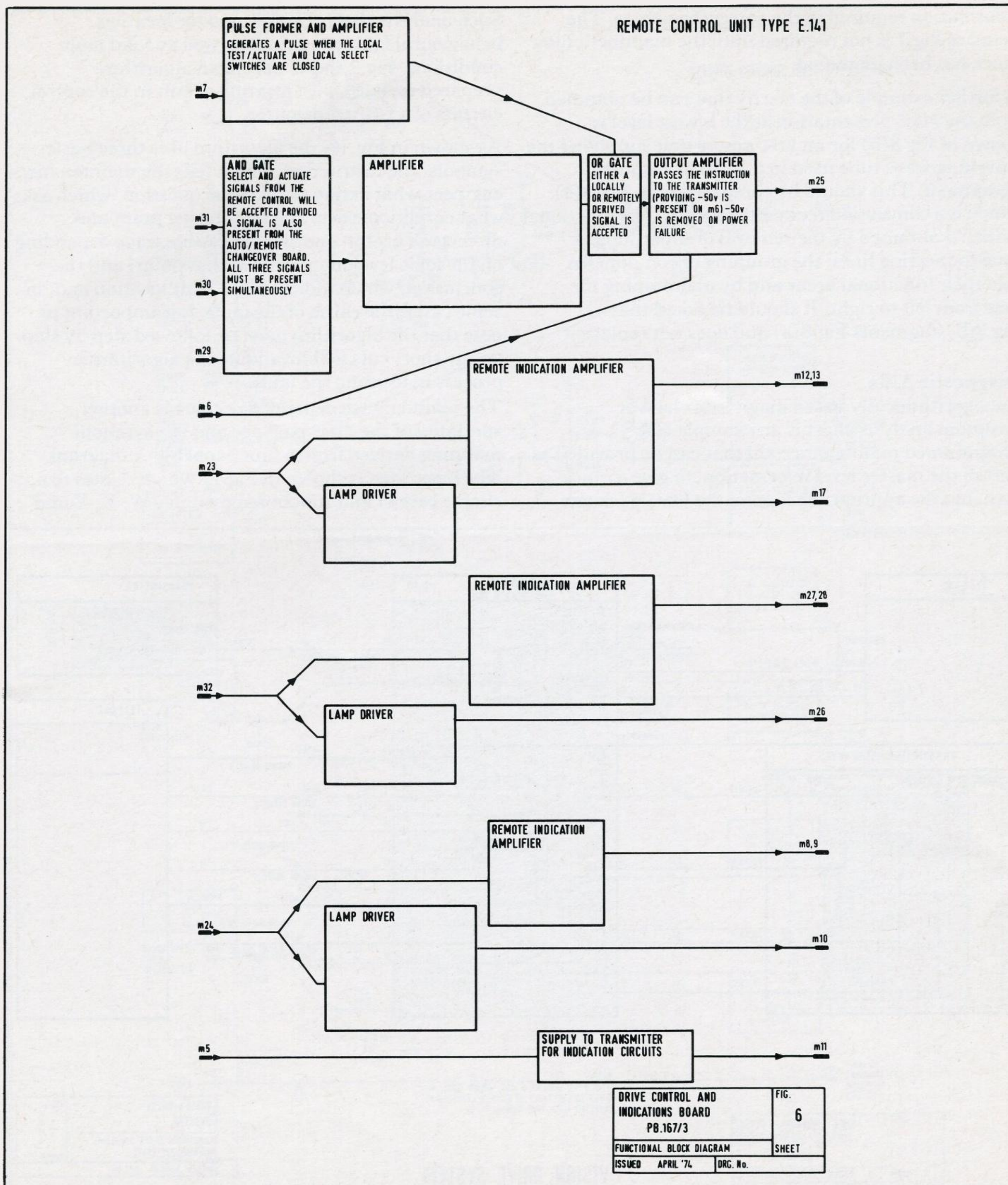


Fig.6. Following on from Fig.5, this is a functional block diagram in which the conventional handbook text is supplemented by notes in certain blocks. This is known as functional block text and it briefly states the functions performed. This figure overlays Fig.7 on the following page which, being at the lowest level, is the functional circuit diagram.

information required in the correct sequence. The detail of Fig.7 is not required until the malfunctioning block has been identified.

A further example of the clarity that can be obtained from the FIMS presentation at the lowest level is shown in Fig 8(b) for an EHT power unit supplying the travelling wave tube used in a 200W transposer equipment. This should be compared with Fig.8(a) which is a conventional circuit diagram. The functional clarity is obtained by the removal of superfluous interconnecting lines, the grouping of components into their functional areas and by maintaining the flow from left to right. It should be noted that Fig.8(b) augments Fig.8(a) and does not replace it.

Diagnostic Aids

An algorithmically based diagnostic chart or symptom analysis chart is an example of a programmed maintenance aid that can be provided as part of the master level information, to give a quick lead into the appropriate level of the FIMS package. Such analysis charts can be used for locating behavioural fault conditions as well as solid fault conditions. Fig.9 shows part of an algorithm prepared to assist with locating a fault in the control circuits of a UHF transmitter.

As shown in Fig.10, the algorithm uses three basic symbols: the instruction, which tells the maintenance engineer what action to take; the question, which asks what condition exists at a monitoring point and directs the user in one of two possible ways depending on the logic level monitored at that point; and the conclusion, which indicates the fault location and, in some cases, the cause of the fault. It is important to note that the algorithm must be followed step by step as any short cuts will invalidate the algorithmic process in locating the fault.

The maintenance dependency chart is another speciality of the FIMS package and is a symbolic mapping derived from a functional block diagram. The basic idea is shown in Fig.11 which relates to a simple case of four functional modules W, X, Y and

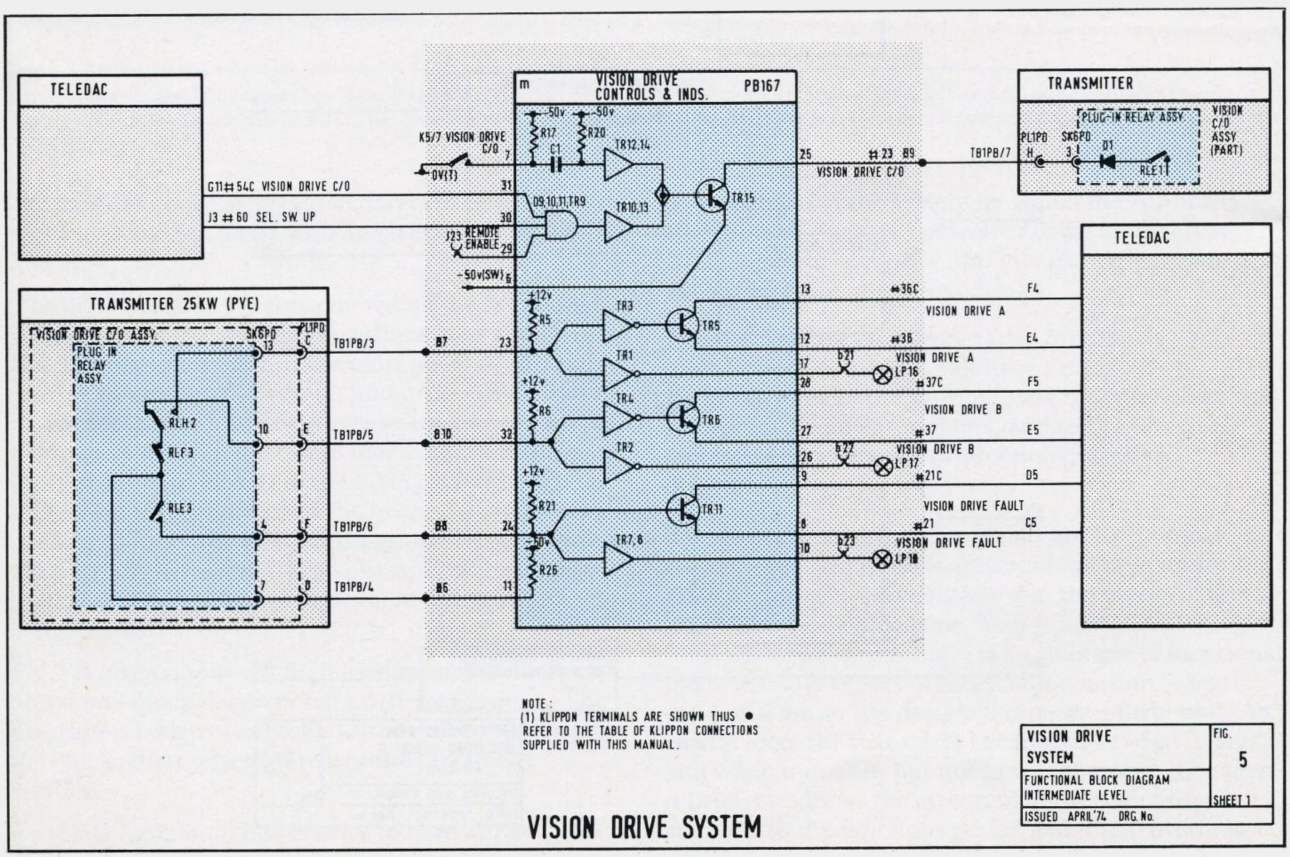


Fig.5. Shown here is an actual systems block diagram of part of the control system for a UHF transmitter. Different items of hardware are shaded grey, but a blue tint is used to denote the functional boundary of the control system. Further information within the central block is given in Figs.6 and 7.

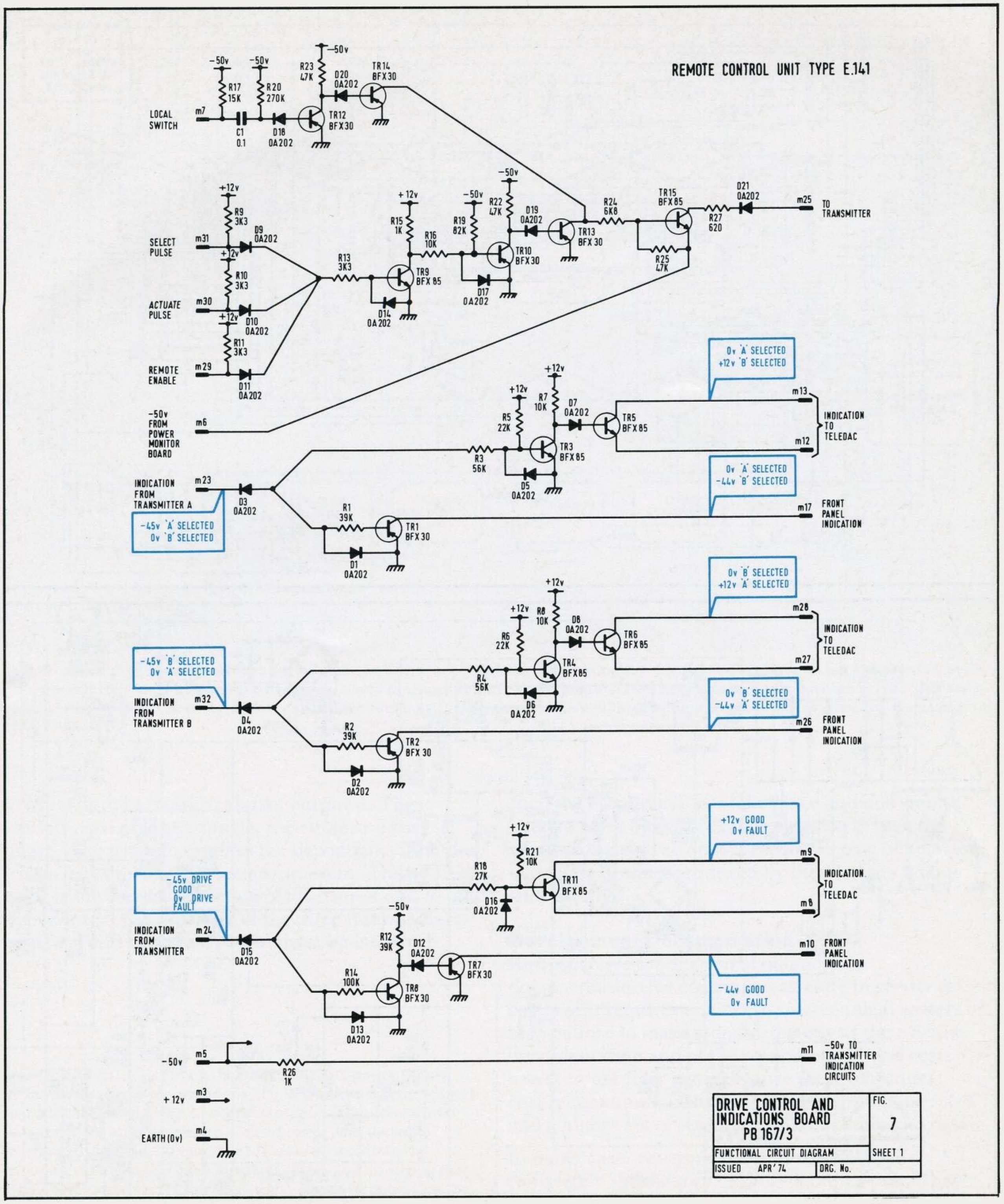
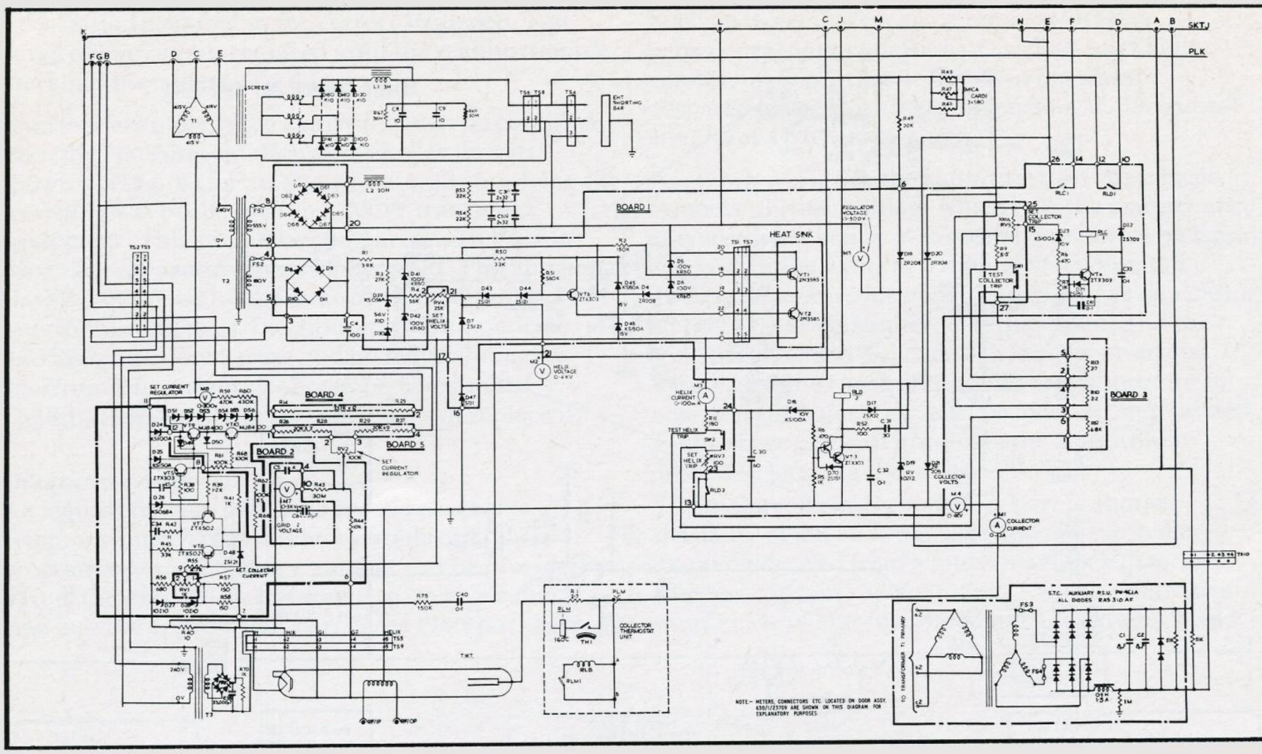
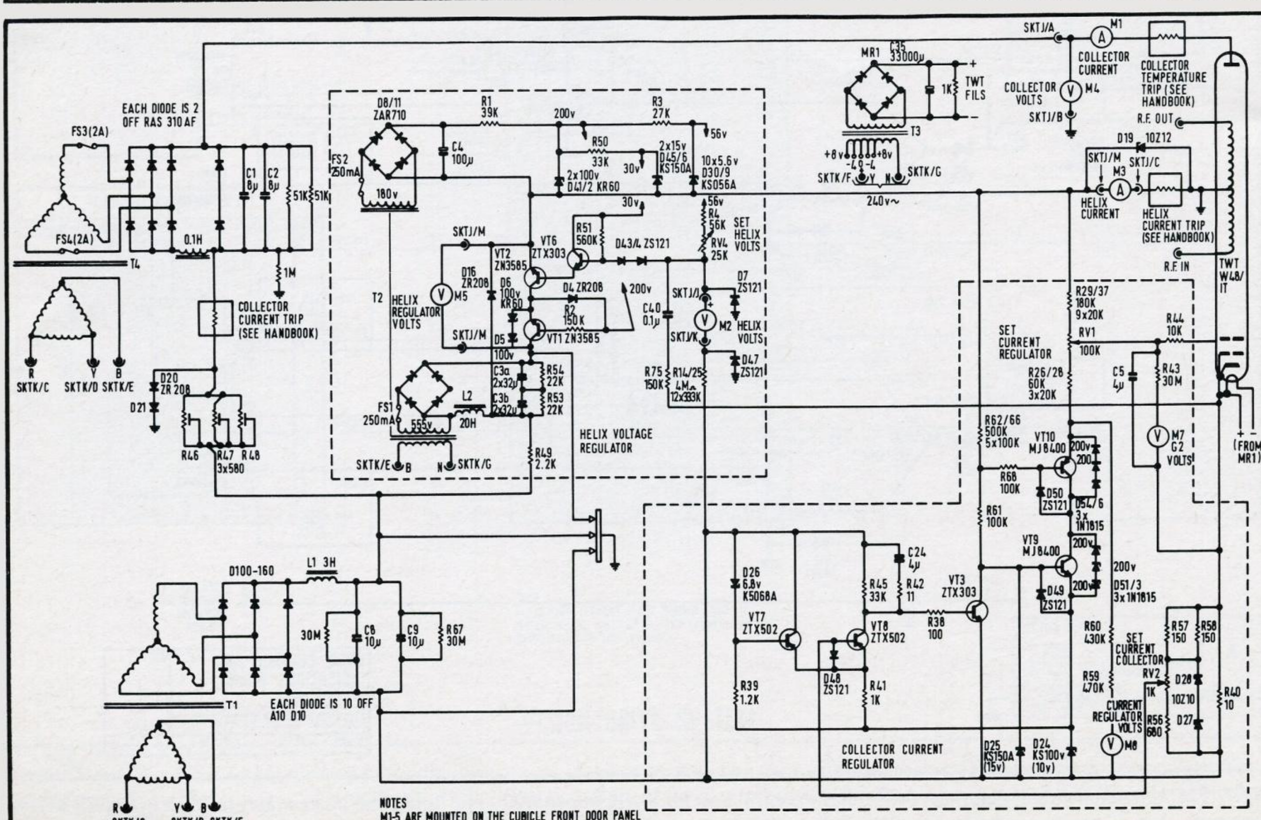


Fig.7. The functional circuit diagram of the remote control unit for a UHF transmitter. The functional block diagram given in Fig.6 overlays the circuit shown here, as can be seen by flicking between the two pages.


SKTJ
PLK
BOARD 1
HEAT SINK
BOARD 4
BOARD 2
BOARD 5
BOARD 3
T.W.T.


EACH DIODE IS 2 OFF RAS 310 AF
FS3(2A)
FS4(2A)
T4
COLLECTOR CURRENT TRIP (SEE HANDBOOK)
SKTK/C
SKTK/D
SKTK/E
HELIX VOLTAGE REGULATOR
HELIX REGULATOR VOLTS
SET HELIX VOLTS
HELIX VOLTS
MR1
TWT FILS
COLLECTOR VOLTS
COLLECTOR CURRENT
COLLECTOR TEMPERATURE TRIP (SEE HANDBOOK)
R.F. OUT
R.F. IN
HELIX CURRENT
HELIX CURRENT TRIP (SEE HANDBOOK)
TWT W48/IT
SET CURRENT REGULATOR
G2 VOLTS
(FROM MR1)
240v~
D100-160
L1 3H
T1
EACH DIODE IS 10 OFF A10 D10
COLLECTOR CURRENT REGULATOR
SET CURRENT COLLECTOR
CURRENT REGULATOR VOLTS
NOTES
M1-5 ARE MOUNTED ON THE CUBICLE FRONT DOOR PANEL

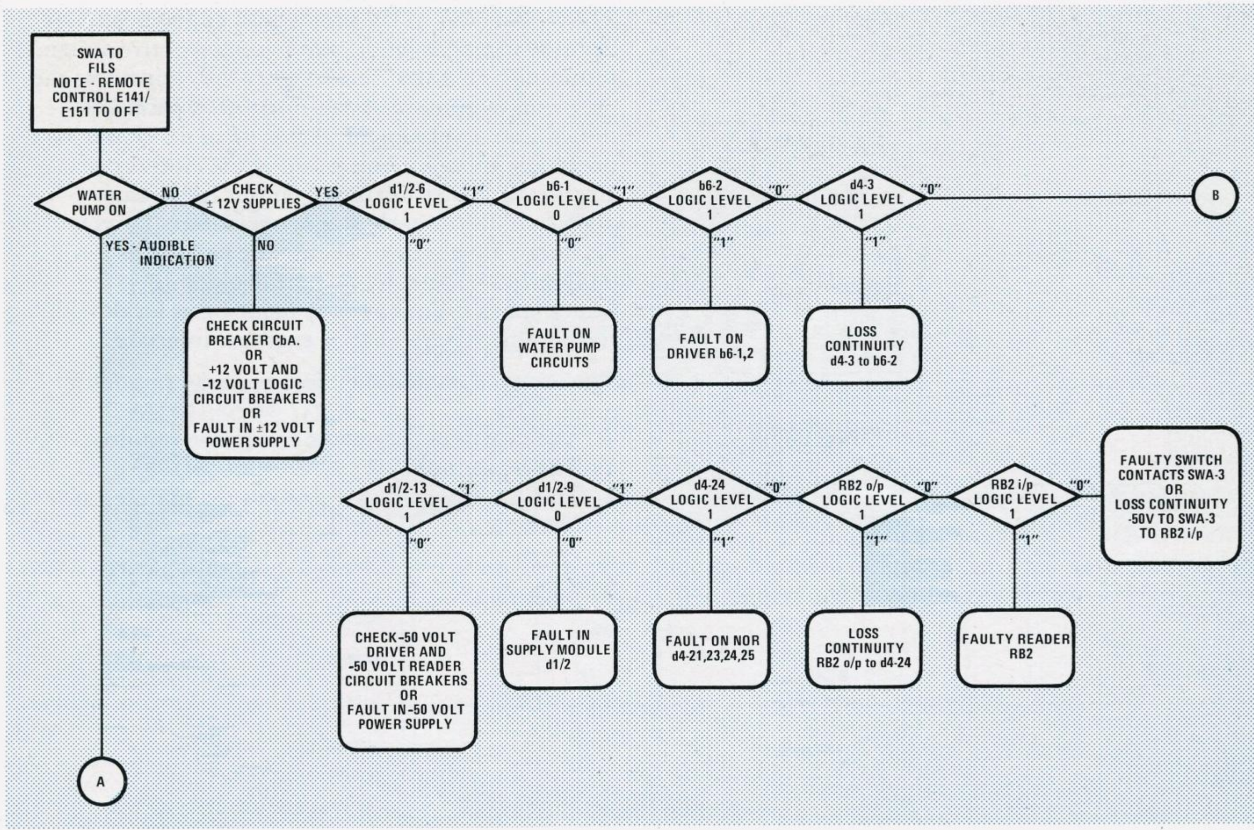


Fig.9. A type of programme maintenance aid that can be included with the information provided at the master level is a symptom analysis chart, alternatively known as an algorithmically based diagnostic chart. The example shown here is part of an algorithm prepared to assist in locating faults that may occur in the control circuits of a UHF transmitter. It is useful in providing a quick lead into the FIMS package at the appropriate level.

Z, three inputs a, b and c and an output d. The symbols used are the triangle, the circle and the square. The triangle signifies the dependency, the circle a function and the square an event. The event d requires the correct operation of function Z and is dependent on the existence of the three intermediary inputs e, f and g. Should any of these be incorrect then the event d will not take place and one would need to work backwards investigating in turn the events e, f, g and so on. Fig.12 shows part of an actual dependency chart produced by the IBA for a colour slide scanner.

Figs.8(a) and (b). The circuit diagram of the EHT power supply unit for the travelling wave tube of a 200 W transposer is the subject of a practical case whereby a FIMS presentation at the lowest level (*below*) provides functional clarity as compared with the more conventional circuit diagram (*above*). This is derived from the regrouping of components into functional areas and arranging that the flow of information is from left to right. It is to be noted that the two diagrams are supplementary and that it is not intended that Fig.8(b) replaces Fig.8(a).

Development Documentation

Retrospective production of diagnostic documentation for equipment already in service is costly as it requires engineers and technical writers of high calibre to make a detailed study of the existing documentation and of the equipment. These costs, however, are fully justified since these tehniques ensure maximum utilisation of the maintenance staff and a higher success rate of fault diagnosis and repair.

In many cases retrospective action is seldom completely satisfactory because monitor points have not been sufficiently well chosen or well sited within the equipment to present the best test strategy.

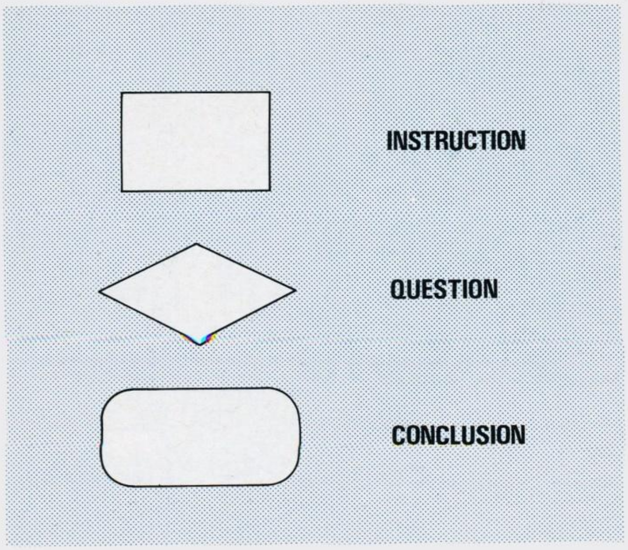


Fig.10. An algorithm such as that given in the previous figure uses three symbols to distinguish between instructions, questions and conclusions.

The real answer to the production of diagnostic documentation is found, not in retrospective action, but by ensuring that the designer fully considers the problems of fault diagnosis during the period of design and development. A system of development documentation is being set up in the Authority's Engineering Division based on this functional approach. In the early stages of a design, ideas will be of a functional nature because the hardware boundaries will not by then be decided. Functionalisation is a ready made basis for developing the designer/maintenance engineer interface.

The designer should therefore consider, amongst other things:

1. The degree of diagnostic resolution required
2. The repair policy
3. The grade of staff carrying out the maintenance functions.

This will ensure that the documentation derived will be most effective.

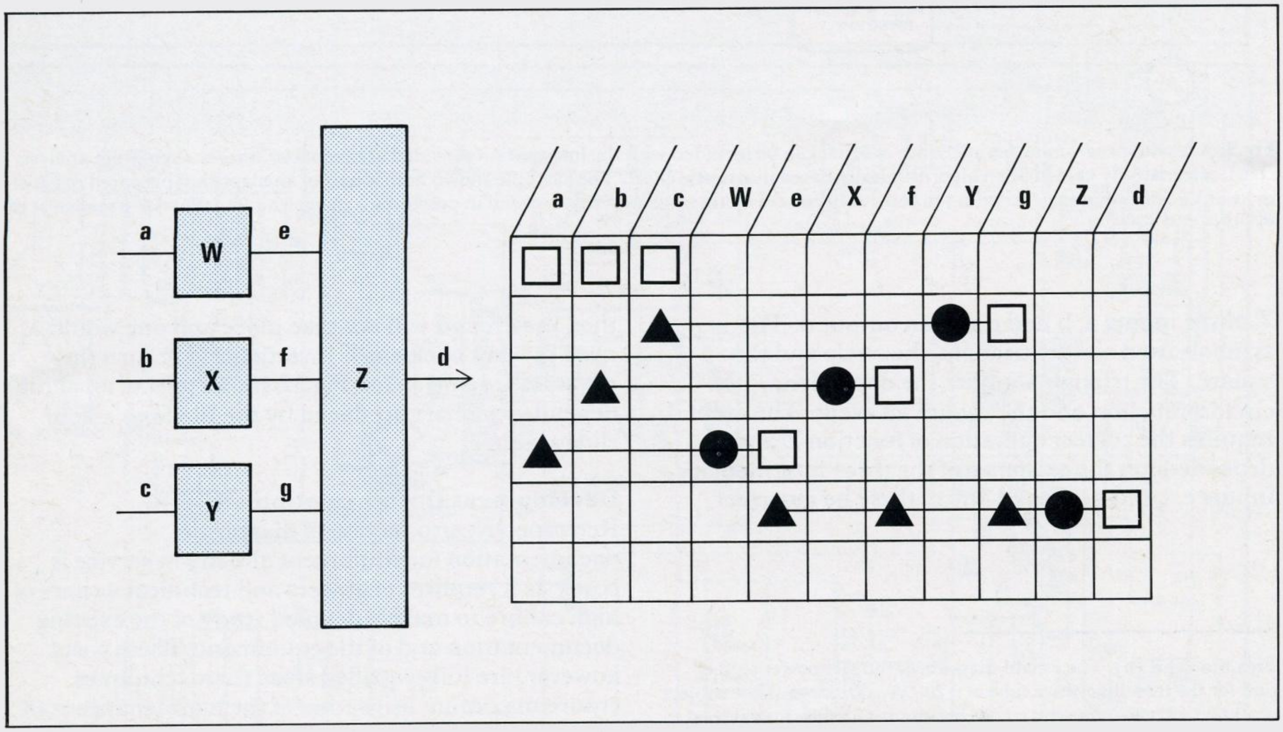


Fig.11. A useful derivative of a functional block diagram which can be included in the FIMS package is the maintenance dependency chart. A simple example of this is illustrated in the figure in which a configuration of four functional modules W, X, Y and Z are fed with three inputs a, b and c and provide a single output d. A dependency is shown with a triangle; a function with a circle and an event with a square. Only if the inputs a, b and c are all present and correct and are operated on by the functions W, X, and Y respectively will the intermediary signals be available for function Z to yield the final output d. Should d not be available, by following the logic in the reverse order the maintenance engineer is led to the item at fault.

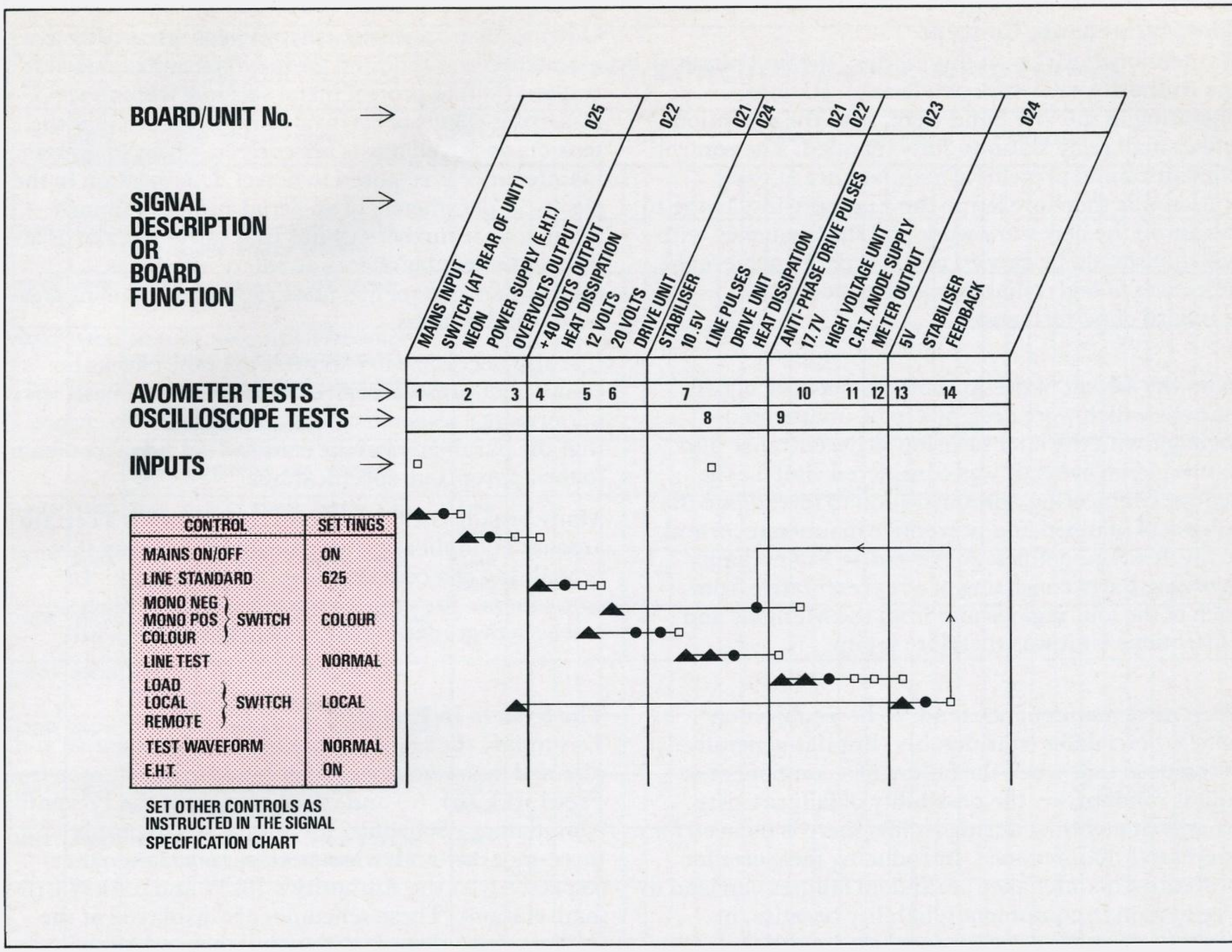


Fig.12. Part of an actual maintenance dependency chart for a colour slide scanner.

The structuring of the diagnostic documentation must be related to the repair policy. The documentation for 'first-aid' action necessary to keep a transmitter on-air can be quite different from that required to ensure that its performance is within the specified limits. Taking the FIMS package as an example, if maintenance in the field is to be carried out by modular replacement, then it is essential that the functional diagrams at the high and intermediate levels are expressed in terms of modules. The lowest level diagrams need only then be produced for the back-up maintenance organisation.

Diagnostic documentation should never be considered as the complete solution to all the maintenance engineer's problems, nor should it be expected to relieve him of the need to think or to apply his skills and engineering knowledge.

PREVENTIVE AND PLANNED MAINTENANCE

Maintenance can be divided into three categories, each with its own specific purpose. The first is to prevent failure by routine checks on units or components on which a predictable rate of wear occurs with the object of replacing any that are nearing the end of their lives. This is called preventive maintenance. The second is to ensure, by the application of systematic checking, that all parts of the equipment are operating correctly and that the overall performance is within the required limits. This is planned maintenance. The third is the detection, location and repair of faults as and when they occur and is known as corrective maintenance. Most equipment calls for all three types, but the following deals only with the first two, i.e. preventive and planned maintenance.

The Maintenance Concept

As mentioned earlier in this edition, the first phase of the Authority's network of television stations operating in the VHF band were, with the exception of a few small relay stations, fully manned. The control of planned and preventive maintenance at each station was therefore left to the Engineer-in-Charge to decide on the necessary work and the frequency with which it should be carried out in order to achieve the objectives of high reliability and an acceptable standard of performance.

With the advent of the Authority's network of UHF stations which were designed to be unattended, together with the later decision to decentralise into four regional areas, it was considered vital for the central engineering administration to investigate the subject of planned and preventive maintenance, and to lay down guidelines. A Preventive Maintenance Working Party consisting of a representative from each of the four regions and from the Methods and Operations Unit was therefore set up.

Preventive maintenance tends to be a subject on which views differ considerably. But it is generally recognised that when the failure of a component or unit is random, i.e. the possibility of failure exists equally at any time during its life, there is no need for preventive maintenance. Introducing measures for preventive maintenance of random failures can lead to a reduction in equipment reliability because, in general, the more interference there is with the normal operation of such equipment the less reliable it becomes. Routine checking cannot protect against random failures, and so preventive maintenance can only be applied to components which are approaching or are within their wear-out period, e.g. air filters, bearings, 'O' rings, batteries etc. It is necessary to consider whether preventive maintenance can be avoided, or the periods between which it is carried out can be extended, by either modifying the offending component or the environment in which it operates, e.g. dirt needs to be removed regularly from components if flashovers causing component failure are to be avoided. By modifying the equipment it is possible to extend the periods between cleaning. Recently modifications have been made to the air-cooling arrangements used in the main UHF stations. By choosing large capacity high-efficiency filters a considerable improvement has been achieved in the degree of filtering obtainable, and the periods between which filters need be changed have been extended.

Outside the transmitter environment, preventive maintenance is required for the mast and aerial systems both to protect metal surfaces from the disastrous effects of corrosion and to ensure that the tensions in guyed masts are correct, whilst planned maintenance is required to detect deterioration in the electrical parameters of an aerial system. Planned maintenance further ensures that safety standards are upheld by regular checks on safety interlocks, earthing arrangements, mast rigging equipment and other similar items.

It is also necessary to carry out periodic checks on component protection circuits. Similarly, overall performance tests must be made regularly to ensure that the parameters of the transmitted signal conform to the appropriate specifications.

Many broadcasters build into their systems a certain amount of duplication as a means of reducing the probability of a complete loss of transmission. In consequence the viewer or listener is more likely to receive a degraded signal rather than none at all.

The System in Practice

To simplify the system the activities of preventive and planned maintenance are combined as can be seen from Figs.13(a), (b), (c) and (d). These show the Preventive Maintenance Schedules for annual, six-monthly, three-monthly and 'when necessary' maintenance respectively at the Authority's 10kW and 6¼kW UHF main stations. These schedules are displayed at the stations and are used in planning the work of the mobile maintenance teams. The schedules have a life of four years, and provision is made for additional work to be added as and when necessary. Each schedule lists the main activities and refers the user either to the Summary of Work, (an example is shown in Fig.14 in respect of the items forming the 12-monthly schedule of Fig.13(a), or, if greater detail is required, to a Station Maintenance Procedure of which a typical example is reproduced in part in Fig.15. All the performance tests detailed on the Preventive Maintenance Schedules of Figs.13(a), (b), (c) and (d) are periodic tests additional to those carried out whenever the station is visited, though never are they applied more often than once a month.

Conclusion

The methods of documentation outlined above have been introduced in the IBA and are proving superior to earlier methods of presenting maintenance information. In particular, the reduction in the

PYE UHF - 10KW & 6¼KW Tx's + STATION				PREVENTIVE MAINTENANCE SCHEDULE (P.M.S.)	Iss
SUMMARY OF WORK P. 3.4.12					Da
12 MONTH VISITS					Ap
ITEM No	SDR SUB-UNIT CODE	JOB DESCRIPTION	REF. No.	VERTICAL INTERVALS = 1 MONTH	
12/01	ASOO	CHECK CALIBRATION OF VISION AND SOUND POWER METERS			
12/02	APOO	CHECK CALIBRATION OF SOUND DEVIATION METER.			
12/03	ASOO	MEASURE AMPLITUDE/FREQUENCY RESPONSE OF SOUND TRANSMITTERS			
12/04	ASOO	MEASURE GROUP DELAY PERFORMANCE OF VISION Tx's REGIONAL EQUIPMENT			
12/05	ASOO	TEST FOR RADIATION LEAKAGE FROM KLYSTRONS AND FEEDERS			
12/06	ASOO	TEST Tx ELECTRICAL INTERLOCKS	S.M.P. P3.4.2		
12/07	RCOO	TEST Tx REMOTE CONTROL AND INDICATIONS	S.M.P. P8.1.2		
12/08	SHOO	MEASURE MICROWAVE Rx's CRYSTAL CURRENT. INPUT LEVELS.			
12/09	ASOO	MEASURE Tx INCIDENTAL PHASE MODULATION. REGIONAL EQUIPMENT			
12/10	ASOO	INSPECT LAGGING AND CONNECTORS ON STEAM PIPE WORK.			
12/11	ASOO	REPLACE RUBBER SEALING RINGS ON KLYSTRON BOILERS	S.M.I. M.3.1.		
12/12	ASOO	TEST 4 CHANNEL C.U. PROTECTION EQUIPMENT - IBA LANDLORD SITES	S.M.P. P2.2.1.		

Fig 13(a)

volume of text and the introduction of functional diagrams have been welcomed. Other aspects of maintenance documentation are being constantly explored in order to provide engineers in the field with the information they require in the form they require it.

Preventive maintenance increases reliability by predicting failures if not always preventing them. It can be justified in terms of the financial savings achieved. Planned maintenance, on the other hand, although its benefits are not so easily quantified, is nevertheless essential to achieving a high standard of performance and good engineering practice.

PYE UHF - 10KW & 6¼KW Tx's + STATION				PR
SUMMARY OF WORK P. 3.4.12				
6 MONTH VISITS				
ITEM No	SDR SUB-UNIT CODE	JOB DESCRIPTION	REF. No.	
6/01	ASOO	MEASURE SOUND AND VISION CARRIER FREQUENCIES.	S.O.I. Q.4.1.	
6/05	PIOO	E.162-MK 2 CHECK FREQUENCY OF LOCAL OSCILLATOR		
6/08	APOO	LUBRICATE DRIVE CUBICLE BLOWERS.	S.M.P. P10.1.	

Fig 13(b)

PYE UHF - 10KW & 6¼KW Tx's & STATION

SUMMARY OF WORK P.3.4.12 PF

3 MONTH VISITS

ITEM No	SDR SUB-UNIT CODE	JOB DESCRIPTION	REF No.
3/01	ASOO	MEASURE CONDUCTIVITY OF COOLING WATER.	S.M.1 M.3.2
3/02	ASOO	INSPECT WATER AND STEAM SYSTEMS FOR LEAKS.	
3/03	ASOO	CHECK COOLING WATER FLOW AND METERS.	
3/04	ASOO	CHECK OPERATION OF WOODS 18" FAN IN Tx EXHAUST TRUNKING.	
3/05	ASOO	TEST 50V Tx CONTROL CCT ISOLATING DIODES IN TEST & BALLAST LOAD COOLING UNIT.	
3/06	ASOO	CLEAN KLYSTRON GUN AND MOD ANODE CERAMICS.	S.M.1 M.3.1
3/07	ASOO	GAS TEST SPARE EEV KLYSTRON	S.M.1 M.3.1
3/08	ASOO	CHECK TEST AND BALLAST LOAD COOLING INTERLOCKS.	S.M.1 M.3.2
3/20	ASOO	FOUR CHANNEL C.U. CHECKS ON IBA LANDLORD SITES.	S.M.1 M.2.1
3/30	RC40	EXAMINE PACKS TAPE & CLEAN HEADS.	

Fig.13(c)

PYE UHF 10KW & 6¼KW Tx's + STATION

SUMMARY OF WORK P.3.4.12 PF

ITEM No	SDR SUB-UNIT CODE	JOB DESCRIPTION	REF No.
		BEFORE ANY MAINTENANCE	
0/01	ASOO	TEST Tx SAFETY INTERLOCKS AND EARTH.	S.A.1. A.5.1.
		WHEN STATION IS VISITED	
0/20	ASOO	READ FILAMENT HOUR METERS	
0/21	EB05	CHECK CONDITION AND CHARGE OF BATTERIES.	
		AT E.I.C.'s DISCRETION	
0/30	ASOO	AGE SPARE KLYSTRON	S.M.1. M.3.1.
0/31	ASOO	TOP UP, KLYSTRON WATER COOLING TANKS.	S.M.1. M.3.2.
0/32	ASOO	CLEAN OR REPLACE AIR FILTERS	
0/33	ASOO	GENERAL Tx CLEANING.	S.M.P P.3.4.3

Fig.13(d)

Figs.13(a), (b), (c) and (d). The Preventive Maintenance Schedules for 12-monthly, 6-monthly, 3-monthly and 'when necessary' activities include main items of both preventive and planned maintenance. The set reproduced here relates to a 10kW/6¼ kW UHF transmitter, and there is provision for further items to be added if needed. For further information reference is given in the appropriate Summary of Work sheets and, where greater detail is required, to a Station Maintenance Procedure (see Figs.14 and 15).

Acknowledgement
The Author would like to express his appreciation to his colleagues in the Station Operations and Maintenance Department for their work in pioneering this form of documentation, and to the members of the Preventive Maintenance Working Party whose deliberations have formed the basis for the work described in this article.

STATION MAINTENANCE PROCEDURES

S.O. & M. DEPARTMENT

No: P.3.4.12	
Date: January 1974	
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1.8 **Item 12/01 Check calibration of vision and sound deviation meters**

Calibrate the vision and sound output power meters against the calorimetric test load.

1.9 **Item 12/02 Check calibration of sound deviation meter**

Calibrate the sound deviation meters as detailed in Station Maintenance Procedure.

1.10 **Item 12/03 Measure amplitude/frequency response of sound transmitters**

Amplitude/frequency response of Transmitter must be within the limits set out in Station Maintenance Instruction M.1.1. Appendix II.

1.11 **Item 12/04 Measure group delay performance of vision Transmitters**

Regionally held equipment is required for this item.

The group delay performance of the transmitter must be within the limits shown in IBA Drawing G-414 Issue 2.

1.12 **Item 12/05 Test for radiation leakage from klystrons and feeders**

Test for radiation leakage from the klystrons and feeders using a R.F. hazard meter. Radiation leakage at levels well below those measurable with the R.F. hazard meter (e.g. 2V/m) can, under certain circumstances, be troublesome where the performance of the transmitters is concerned. Such low level leakage, manifests itself as variations in response with the position of the cubicle doors, cables and movement of metal objects in and around the klystron cubicle. These variations must not exceed 0.5dB.

1.13 **Item 12/06 Test Transmitter electrical interlocks**

Test the transmitter electrical interlocks in accordance with Station Maintenance Procedure P.3.4.2.

1.14 **Item 12/07 Test Transmitter remote control and indications**

Test the transmitter remote control and indications in accordance with Station Maintenance Procedure P.8.1.2.

1.15 **Item 12/08 Measure microwave receiver's crystal current input levels**

Record meter readings and investigate any discrepancies with previous readings.

Fig.14. Summary of Work sheet covering the first eight items shown on the 12-monthly Preventive Maintenance Schedule reproduced in Fig.13(a).

STATION MAINTENANCE PROCEDURES

STATION OPERATIONS AND MAINTENANCE DEPARTMENT

Reference	
P.3.4.2	
Date NOVEMBER, 1972	
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PYE 10kW/6¼kW UHF TRANSMITTERS CHECKS ON PROTECTION INTERLOCKS

CONTENTS

APPENDICES

INTRODUCTION

This procedure details tests on Pye 10kW/6¼kW u.h.f. transmitters to check the circuits that monitor the state of the air, water and electrical supplies. It also provides checks on circuits that monitor the transmitter output power.

The checks are to be carried out in accordance with the Preventive Maintenance Schedule (ref. item 3.9).

App. 1 gives tests for the interlocks and alarms on the feeder switching frame.

IBA

Fig.15(a)

Reference P.3.4.2	
Date NOVEMBER, 1972	
Issue 1	Page 2 OF 5

STATION MAINTENANCE PROCEDURES

STATION OPERATIONS AND MAINTENANCE DEPARTMENT

1 **GENERAL**

The following tests are to check circuits which are not used in normal transmitter operation, i.e. are only effective when the transmitter develops a fault. As a result of these circuits not being in regular use, any fault(s) which may develop on them can go unnoticed and could lead to a transmitter not being protected against a fault and serious damage being caused.

The tests apply to one transmitter pair (sound and vision) only and should be performed separately on each transmitter pair. The tests are written in a recommended sequence and should be performed from start to finish, rather than performing individual tests. If individual tests are required, please ensure that all preparatory and resetting steps are taken.

2 **TESTS**

2.1 LAMPS

(a) Press LAMP TEST button and check that all lamps light.

2.2 AIR

(a) Switch transmitter to BEAM and wait until BEAM lamp lights.

(b) Switch off cubicle blower.

(c) After a short delay, for blower to run down, check that AIR lamp goes out and then FILAMENT, FOCUS SOUND and VISION, DELAY and BEAM lamps go out.

(d) Switch on cubicle blower and run transmitter back until all lamps, including BEAM, light.

(e) Switch off combining unit blower.

(f) Check that AIR lamp goes out and then FILAMENT, FOCUS SOUND and VISION, DELAY and BEAM lamps go out.

(g) Switch on combining unit blower and run transmitter back until all lamps, including BEAM, light.

(h) Remove combining unit air filter and momentarily release air paddle switch, where fitted, checking that AIR lamp momentarily goes out; check that no other lamps go out and that all works correctly. Where no air paddle is fitted, remove an output cavity air feed momentarily, checking that the AIR lamp momentarily goes out and all works correctly.

(i) Switch off transmitter and check that blowers stay on for 5 minutes.

2.3 FILAMENTS

(a) Switch transmitter to BEAM.

(b) Check that FILAMENT lamp lights after 30 seconds.

(c) Check that DELAY and BEAM lamps light 4.5 minutes after FILAMENT lamp.

2.4 CHEATER SWITCH

(a) Operate the cheater switch.

(b) Check that the FOCUS SOUND and VISION lamps light and, after 4.5 minutes, the DELAY lamp lights.

(c) Close the cheater switch cabinet door and check that the FOCUS SOUND and VISION lamps go out.

2.5 WATER

(a) Operate logic cheater switch and switch transmitter to BEAM.

(b) Disconnect float interlock plug on sound klystron trolley.

(c) Check that WATER LEVEL lamp lights and beam contactors release.

(d) Turn off klystron water pump and check with Avo (on continuity) across float plug for an open circuit at nominal minimum float level setting.

(e) Reconnect float interlock plug and turn on klystron water pump.

(f) Check that WATER LEVEL lamp goes out.

(g) Repeat sub-paras. (b) to (f) for the vision klystron.

(h) Switch transmitter to REMOTE and switch off klystron water pump.

(i) Check that transmitter switches off after approximately one minute.

IBA

Fig.15(a) and (b). Part of Station Maintenance Procedure referred to against item *12/06 Test on Electrical Interlocks* of the 12-monthly Preventive Maintenance Schedule reproduced in Fig.13(a).

LES SHERRY joined the Authority in 1961 after serving an apprenticeship with the Post Office, and worked at several television transmitting stations before taking up his present post of Senior Engineer in the Maintenance Section. He has a Higher National Certificate in Electrical Engineering and leads a group of engineers who provide a maintenance support service for remote control, monitoring and programme input equipment. This group is also responsible for providing mobile maintenance and for test equipment used when commissioning stations. He is married with two children and is at present spending his spare time renovating his first (and probably last) classic car.

Mobile Maintenance Test Equipment

by L A Sherry

Synopsis

Maintaining a broadcasting network designed for unattended operation requires test equipment which can be set up quickly on site by teams of mobile maintenance engineers and which can be easily transported from station to station. It must also be of a calibre and accuracy sufficient to maintain the broadcasting equipment to the high standards of performance required by the Independent Broadcasting Authority as published in the various IBA Codes of Practice. Moreover, the location of many of the transmitter sites is so remote that access is possible only by means of vehicles such as Range Rovers and this naturally imposes a limit on the volume of test equipment that can be carried.

The following article outlines the way in which the IBA has approached the problems of mobile maintenance test equipment and briefly describes each item of test equipment used.

Introduction

At its various transmitter sites throughout the United Kingdom, most of which are unmanned and located at very remote sites, the Independent Broadcasting Authority operates and maintains many kinds of electronic equipment which have been acquired during two decades. These, therefore, cover a diversity of technologies and range from equipment using time-honoured all-valve circuits to the most up-to-date microprocessors.

The responsibility for maintaining all this equipment rests at the present time with 26 mobile maintenance teams operating from 23 bases. On average, each mobile maintenance team is responsible for equipment at 12 locations and so is likely to have to deal with the full cross-section of the various technologies mentioned.

To meet this maintenance commitment each mobile maintenance team consists of two engineers equipped with a two- or four-wheel drive estate car and a complement of test equipment sufficient to assist in diagnosing faults and adjusting the performance of most of the equipment encountered.

The extent and quality of the test equipment carried by each team is determined by experience in establishing the high standards of performance required by the Authority for all its broadcasting equipment. In order to gain this experience the first six mobile maintenance teams set up by the Authority at the commencement of the UHF colour television service in 1969 were each equipped with a very comprehensive selection indeed. This allowed teams to deal with virtually every fault and alignment problem irrespective of the frequency of its occurrence. Thus, there was a very low utilisation of certain items and also a transportation problem in that 30 cwt. vans were required for moving the equipment from site to site. It soon became clear that this method of transportation was unsuitable for two reasons. First, the maintenance engineers were

required to drive the vehicles and, with some locations being as much as 100 miles from their base, human fatigue was a significant problem in that the engineers were expected to tackle complicated diagnostic maintenance problems after having been driving a heavy van for some two to three hours. Second, as the number of operational stations increased, the cost of metalled access roads to the more remote sites became prohibitive. At that stage it became more economical to provide the teams with four-wheel drive vehicles which could traverse fields, streams and washed-out mountain tracks (see Fig.1) rather than to lay and maintain metalled access roads. However, those early years provided valuable information on which to form a policy for providing test equipment based on utilisation. From an analysis of maintenance engineers' 'visit reports' it was possible to determine the relative amount of time each item was used. From this information the equipment was separated into two groups; that which was used frequently was retained on the strength of the team, while that which was used infrequently was transferred to the control of four regional centres to be shared on demand by several different teams. Each team, therefore, now has

Fig.1. The total number of transmitter stations is constantly growing and those in the more remote locations are frequently difficult of access. The cost of providing metalled access roads in such locations can exceed that of the station itself, but can be avoided by the use of four-wheel drive vehicles capable of negotiating the sort of rough terrain which often separates a transmitter from its nearest approach road. The Range Rover shown here is typical of that used for mobile maintenance purposes where a site access problem exists.

a measuring capability related to the frequency at which the need for such measurements occur.

Further reduction in weight or volume of test equipment can be achieved in several ways, the most obvious being that of continually surveying the market for equipment which, while meeting the measurement requirements, can also offer a reduction in physical dimensions. An alternative approach is to develop and produce in-house test equipment which exactly meets the needs of mobile maintenance; but, because of the very small number of production units required, this can be very costly and the Authority adopts this approach only when no suitable commercial equipment is available. However, by following the first method and by persuading manufacturers to modify certain items of standard equipment to meet additional requirements, thus eliminating the need for supplementary items, worthwhile reductions in volume and weight have been successfully achieved. Further reductions in the weight and volume, and indeed the cost, of test equipment carried by the mobile units have resulted from developing new methods of testing which require the minimum number of different items of test gear.

Basic Inventory

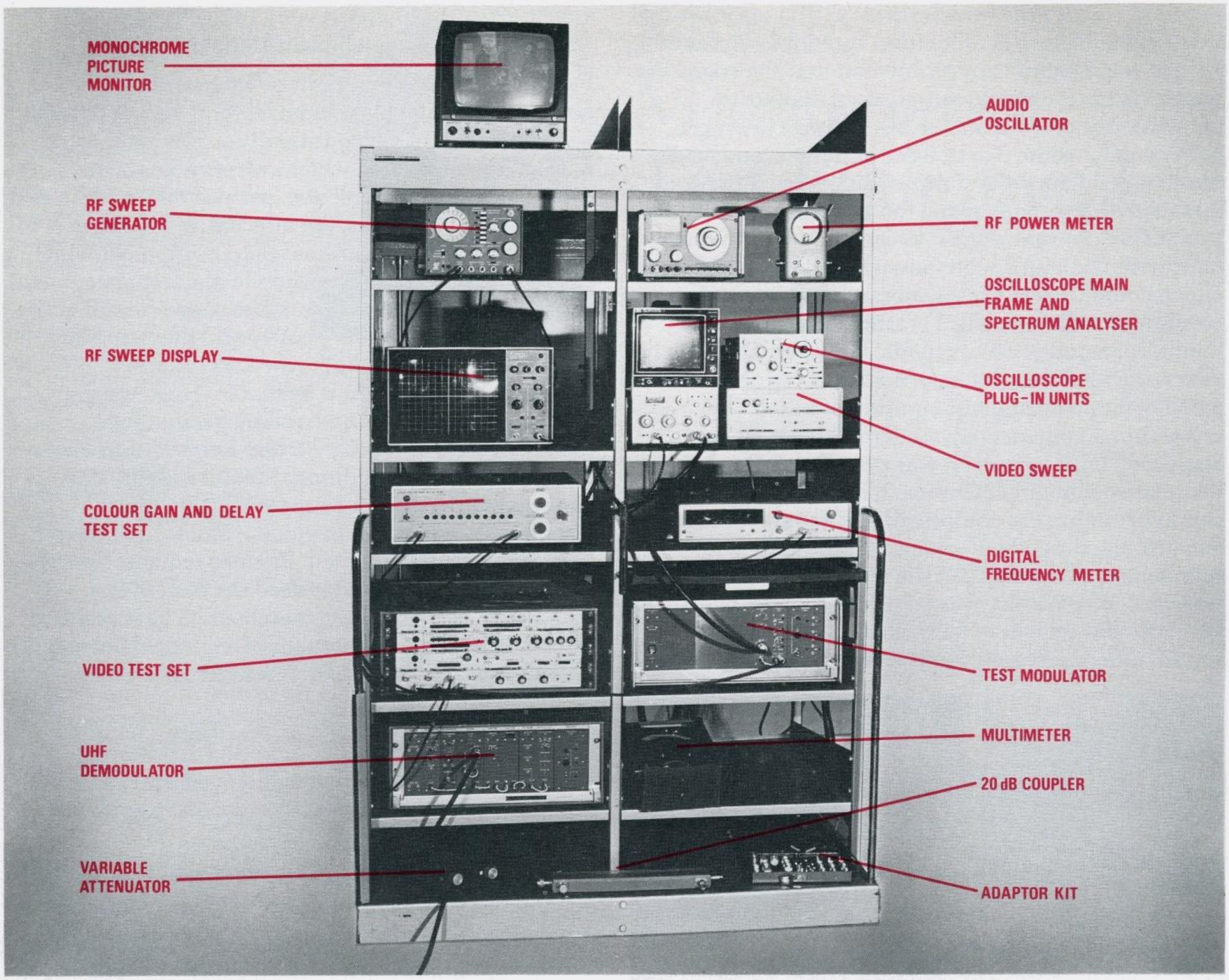
The foregoing factors have influenced the choice of equipment and have led to the current range which is now considered in detail.

The test equipment carried by each team weighs 230 Kg and has a packed volume of 1.25 m^3. These figures are increased by about 5 per cent in the case of any team having a local radio involvement. The usual vehicle for carrying this load is a Volvo estate car, but a Range Rover is available in the event of there being a site access problem. Fig.2(a) illustrates the equipment supplied to teams with a television commitment, and Fig.2(b) shows the additional items required by a team having responsibility for both television and radio.

The following is a list of the complete equipment carried by each team together with a brief description of its measuring capability.

Spectrum analyser and oscilloscope system. This equipment is a measuring system comprising essentially an oscilloscope frame into which a spectrum analyser plug-in module may be fitted as an alternative to the normal oscilloscope module.

The spectrum analyser module has an operating frequency range of 100 kHz to 1500 MHz, a resolution ranging from 3 MHz to 1 kHz and a dynamic range of 107 dB. Its principal measuring functions are:

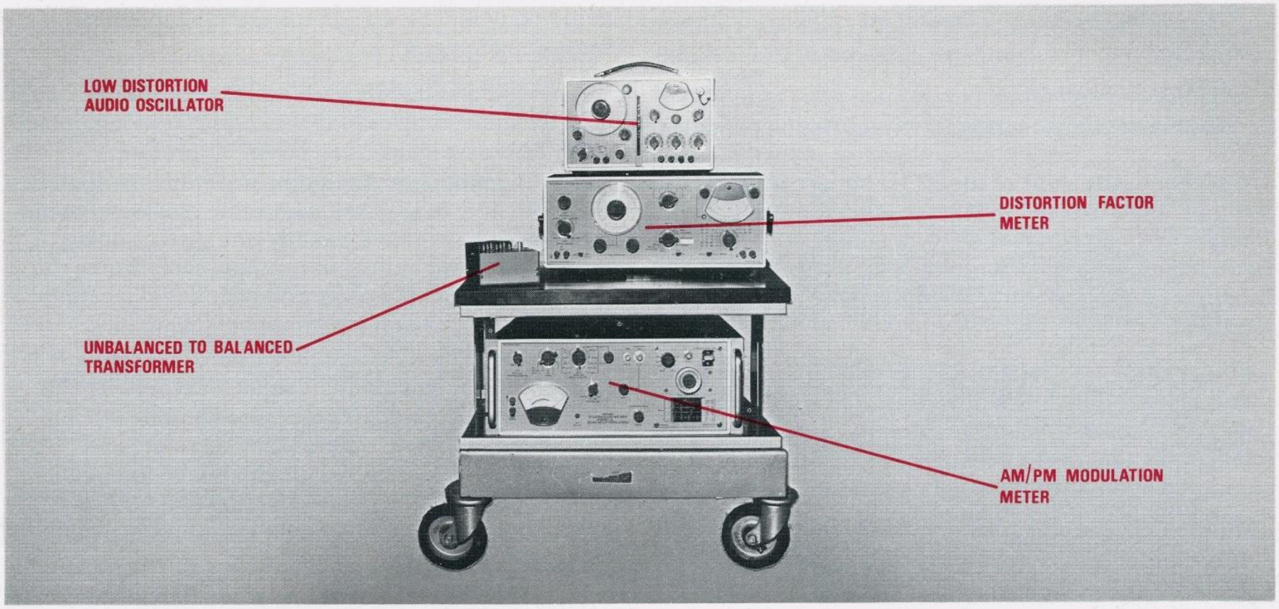


- Selective signal amplitude measurement in the range −117 dBm to +30 dBm
- Display of transmitter sideband response
- Measurement of intermodulation products
- Measurement of vision-to-sound cross modulation
- Measurement of spurious signals
- Display of carrier amplitude of a modulated FM signal for measurement of deviation
- Measurement of AM modulation depth
- Measurement of relative carrier and sideband amplitude (vision, chroma and sound)
- Measurement of subliminal continuity and stereo pilot tone amplitude

The oscilloscope plug-in units provide a dual-channel Y-amplifier with a 50 MHz bandwidth and 5 mV/division sensitivity, (1 division = 1.29 cm approximately). The time base plug-in has main and delayed sweeps with sweep rates from 1s/division to 50 ns/division. Requests to the manufacturers for a means of triggering from line and field sync pulses has provided a standard feature on the timebase which now allows full inspection of the television waveform including measurement of field interval test signals. This small modification to a standard item of equipment has eliminated the need for carrying a separate waveform monitor.

On its own the oscilloscope is used for the following main functions:

- Signal amplitude measurement in the frequency range DC to 50 MHz
- Measurement of waveform distortions on line-repetitive and field-interval test signals



Figs.2(a) and (b). Fig.2(a) *left* shows the current range of test equipment supplied to mobile maintenance teams having a television commitment only. If the commitment includes maintenance of local radio stations, additional equipment is required as shown in Fig.2(b). Where site access is normally good, vehicles used for carrying all these various items (though naturally not the test trolleys) are Volvo estate cars; in other cases Range Rovers are used.

- Timing measurements of television and other waveforms
- Display of linearity, differential gain and differential phase waveforms from a video test set
- Measurement of video signal-to-noise ratio
- Display of modulated IF carriers for inspection and measurement of amplitude.

UHF measuring demodulator. The UHF measuring demodulator provides no measuring function as such but demodulates sound and vision carriers to a high order of performance enabling sound and television waveform measurements to be made using conventional methods. Most of these demodulators in use at present incorporate envelope detectors which produce quadrature distortion of the vision signal. This distortion can be quantified, and suitable allowances taken into account when making measurements, but demodulators incorporating synchronous detectors which overcome the quadrature distortion problem are now becoming available and will be supplied in future.

This type of demodulator is not tunable and so appropriate plug-in RF heads are retained at each transmitter station.

Picture monitor. A quality monochrome picture monitor can be fed from the output of the measuring demodulator and used for assessing the subjective effects of those distortions which can occur in a television system and which are either difficult to measure or cannot be easily related to the corresponding subjective impairment. Such distortions are:

- Patterning due to spurious frequencies
- Co-channel interference
- Delayed images and ghosting
- HF to LF noise conversion
- PAL ripple (colour burst)

There has never been any need to carry a colour monitor as distortions affecting the colour signal can be adequately identified by direct measurement.

Video test set. This consists of commercially available items of video generating and measuring equipment which have been combined and packaged by the manufacturers in accordance with an IBA specification. The following test waveforms can be generated:

- Five- or ten-step line-repetitive greyscale
- CCIR greyscale
- Sawtooth
- Monochrome pulse-and-bar (2T or T)

Composite chroma pulse-and-bar (10T or 20T)
Chroma only pulse-and-bar (10T or 20T)
50 Hz square wave
Waveform for measuring intermodulation products.

In addition, the slope of the 50 Hz square waveform may be tilted in order to test the effectiveness of transmitter clamps, and the sync pulses of the waveforms reduced in amplitude by a specified amount in order to test transmitter sync regeneration circuits.

A block diagram illustrating the functions of the test set is given in Fig.3. It will be seen that these functions include the measurement of linearity, differential gain and phase, and that a general purpose oscilloscope is used to display the measured parameter.

Additional switching is built into the test set to enable an additional waveform generator and a chrominance gain and delay test set to be integrated into the measuring system.

Chrominance gain and delay test set. This equipment can be used for measuring chrominance-luminance gain and delay errors on a video test signal. It produces calibrated amounts of gain and delay error which can be added to a 10T to 20T composite test waveform in such a way as to cancel exactly any gain or delay errors which might be present. However, due to the large amount of chrominance-luminance crosstalk produced by a vestigial sideband transmission demodulated by an envelope detector, chrominance-luminance gain inequality can be measured by this method only if the degree of crosstalk is known and due allowance made. In practice, therefore, the instrument is used only to measure delay inequality; gain inequality is measured by direct inspection of an interval test signal waveform or chrominance pulse-and-bar.

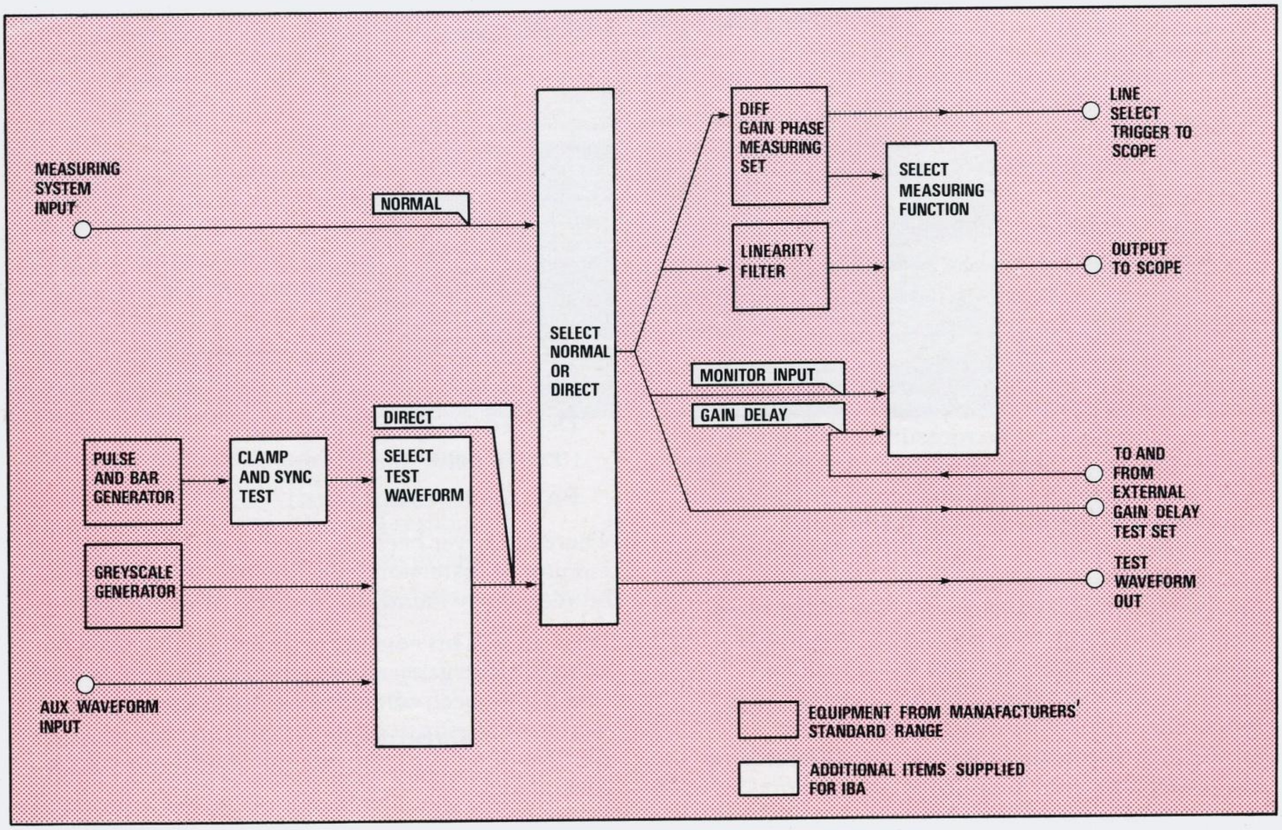


Fig.3. In order to make the full range of video measurements that are necessary at any location, various items of generating and measuring equipment would have to be set up and connected to form a different configuration for each individual test. In a mobile maintenance environment the time taken in doing this setting up and interconnecting can be equal to or longer than the time needed to make the measurements. The video test set consists of a number of standard items of commercially available test gear with switching arrangements as specified by the IBA to enable the complete range of video tests to be carried out once the initial interconnections have been made. Physical sizes are compared in Fig.5.

RF sweep generator and display. The generator provides an RF sweep in the range 1 to 1500 MHz. It is used in measuring and adjusting the amplitude-frequency response and the return loss of RF circuits used in transmitters and transposers.

It is a manufacturer's standard product and has no feature specifically related to television measurements.

Video sweep generator. The primary function of the video sweep generator is the measuring of transmitter sideband response in conjunction with a spectrum analyser. It is used also to measure the amplitude-frequency response of video circuits. The unit produces a sweep from 25 Hz to 6 or 10 MHz, repeating at television field frequency, which can be superimposed on variable average picture level. It also generates composite syncs.

Test modulator. A test modulator is required for the testing of transposers. A transposer receives a television signal off-air from a main transmitter. The received signal is amplified, transposed on to another channel, and then rebroadcast. To test a transposer it is necessary to simulate the main transmitter in order to provide an input signal. This could be done by means of signal generators, but it is more convenient to use a purpose built test modulator which allows all the usual video tests to be made. Also, the test modulator is able to generate three carriers (sound, vision and chroma) at standard levels for measuring intermodulation products.

Digital frequency meter. This is provided specifically for measuring transmitter carrier frequencies. The type usually supplied is a direct reading instrument having a frequency range of 10 Hz to 1000 MHz and an ageing rate of 5 parts in 10^{10} per day. For this application calibration is required at 6-monthly intervals.

20 dB coupler. When measuring return loss the equipment under test is fed from the RF sweep generator. Its output is then connected by means of a precision 20 dB coupler to the spectrum analyser which gives directly in dB a calibrated display of the return loss.

RF power meter. The power meter supplied for this application operates by taking a small amount of energy from the transmission line to which it is connected.

Coupling elements can be changed to cover a wide range of power levels and frequencies. This latter extends from 450 kHz to 1000 MHz and calibration affords a number of full scale deflections within the range 0·5 W to 2·5 kW.

It also has a peak reading mode so that the peak sync power of a vision carrier, or the peak envelope power of two or more carriers, can be measured.

Carrier levels above 2·5 kW are usually measured with calorimetric power measuring equipment built into the transmitter. In some cases, however, this measurement is made by connecting the RF power meter to the output of a precision coupler built into the transmitter.

Audio oscillator. A simple RC oscillator provides a modulation source for use when measuring depth of modulation and frequency deviation on the spectrum analyser.

Sundry items. Other, more general, items of equipment include a multimeter and sundry attenuators, adaptors, bandpass filters, and a pair of high quality headphones for subjective assessment of sound quality. These have been supplied mainly to avoid the very much greater bulk of a loudspeaker system, and also because they help to exclude the high ambient noise level in transmitting station buildings.

The range of test equipment so far described is that carried by those teams having only a television station maintenance commitment. Teams having the additional commitment of local radio also carry a low-distortion audio oscillator, a distortion factor meter and an AM/FM modulation meter. The purpose of this latter is essentially to enable AM and FM carriers to be demodulated for the measurement of noise, distortion and amplitude-frequency response.

Reserve Equipment

As previously stated, the above inventory of test gear is sufficient to cover the majority of measurements that may be required; but, occasionally, more accurate or more detailed measurements are necessary for solving particular problems. Additional equipment for such purposes is held at each of four regional centres and is, therefore, available on demand to any of several teams.

Regional centres do, in fact, have a range of test equipment that is very comprehensive since they are responsible for commissioning new stations. However, the following describes those items available to the mobile maintenance teams.

Group delay measuring equipment. All UHF transmitters and transposers incorporate group delay correction circuits and the normal complement of test gear is

sufficient for measuring the effect of incorrect group delay correction since it will result in distortion of the pulse-and-bar waveforms. In cases where it is found that distortion of the pulse-and-bar waveforms results from causes other than an incorrect amplitude-frequency response, it then becomes necessary for the visiting team to borrow group delay measuring equipment from the local regional centre.

Synchronous demodulator. A synchronous demodulator has a particularly useful facility in that it can be used for measuring the incidental phase modulation of the vision carrier. Excessive phase modulation of the vision carrier will produce buzz at the output of a receiver using intercarrier circuits. The envelope demodulator normally carried by mobile teams has an intercarrier mode of working which can be used to detect this buzz. However, since intercarrier buzz may result from causes other than incidental phase modulation, a synchronous demodulator is borrowed from the regional centre before any adjustment is made to the transmitter.

True RMS digital voltmeter. The AC filament supply for transmitter valves is often fed via a saturated reactor which can distort the waveform to such an extent that measurement of voltage on a mean-reading meter would not be sufficiently accurate. Similarly, DC filament supplies sometimes contain an amount of ripple sufficient to render a mean-reading instrument inaccurate. For these reasons the meters forming a built-in feature of filament power supplies require periodical checking against a true RMS instrument.

TV noise measuring equipment. The usual method of measuring noise on a television waveform by means of an oscilloscope is only sufficiently accurate to ensure that the system noise produced by several equipments in tandem is within acceptable limits. Should the noise exceed those limits, a more accurate noise measuring system is required for determining the relatively small amounts contributed by each component of the system. When this need arises teams are able to call either on equipment which measures the noise on a line-repetitive test signal, or on alternative equipment which, by using a test line in the vertical interval, enables the measurement to be made during programme transmission.

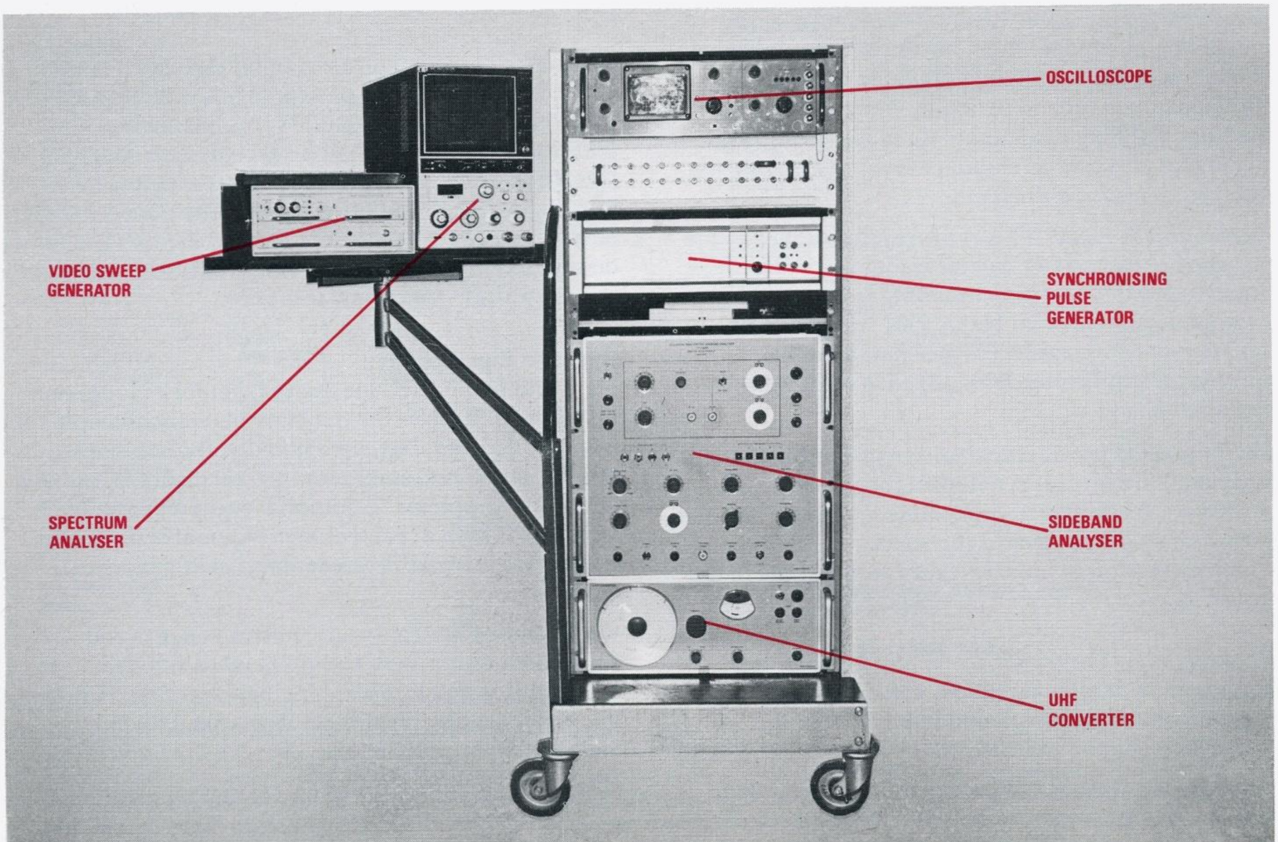


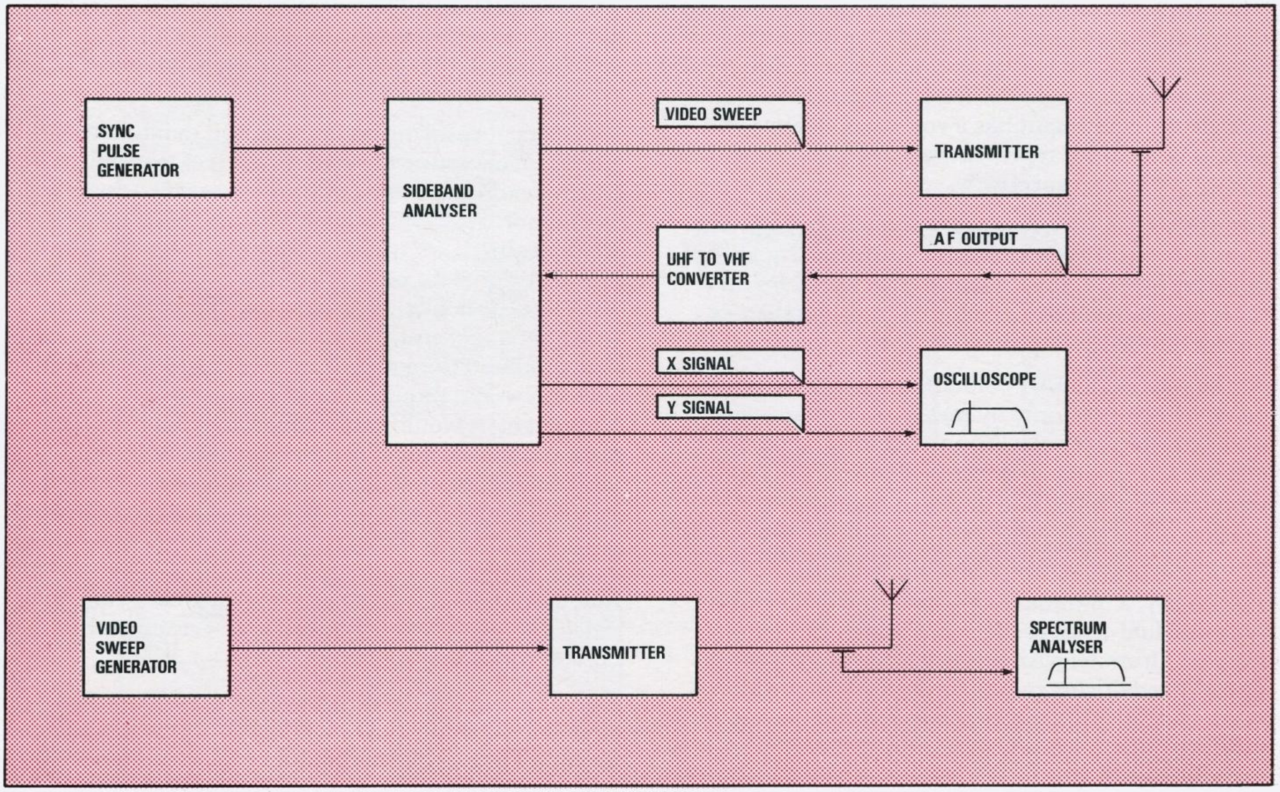
Chart recorder. Intermittent faults on unattended equipment are often difficult and expensive to diagnose as they have a habit of disappearing when engineers appear on site in accordance with a well-known law! Chart recorders are helpful in such instances.

ITS insertion generators and waveform degraders. Each main television transmitting station incorporates automatic monitoring equipment for measuring parameters on the interval test signal and for raising appropriate alarms at the local monitoring centre. Occasionally, this automatic monitoring equipment needs calibrating. Regional centres have portable ITS waveform generators and inserters which may be used to provide 'clean' test signals for the automatic monitoring equipment. These can then be degraded by a pre-determined amount by using a waveform degrader to check the calibration of the automatic monitoring equipment.

Sound test equipment. A low distortion oscillator, a distortion factor meter and an AM/FM modulation meter are available as required to assist in dealing with particular audio problems. As stated earlier, teams having a local radio commitment carry this equipment as part of their standard inventory.

Some Practical Considerations

The conventional IBA method of measuring the sideband amplitude-frequency response of a television transmitter is that of using a purpose-built sideband analyser consisting of a video sweep generator to provide the input signal to the transmitter and a mixer and narrow-band receiver to recover the swept signal from the transmitter output. The receivers available for this purpose accept only a VHF input; hence, a UHF to VHF convertor is needed when dealing with UHF transmitters. Moreover, the video sweep generator requires an external synchronising pulse generator to provide synchronising pulses for the video input waveform, and an oscilloscope is required for displaying the response. Physically, this equipment, including the oscilloscope and



Figs.4.(a) and (b). By developing new methods of testing, the amount and complexity of equipment needed for making the required measurements can be significantly reduced. An example of this is illustrated for the measurement of transmitter sideband response. Fig.4.(a) *left* compares the amount of physical equipment needed when using a conventional sideband analyser (right-hand side) with that required by basing the measurement on a spectrum analyser (left-hand side), and Fig.4(b) *above* makes comparison between the block diagrams for the two methods.

synchronising pulse generator, occupies a volume of $0.1m^3$ and weighs 43 kg.

An alternative method of displaying the sideband response of a transmitter has been developed using a spectrum analyser; and since, as stated above, this device is needed for other measurements and forms a standard item of mobile equipment, considerable savings in cost have been achieved. In this method the spectrum analyser is used to display the output spectrum of the transmsitter when modulated with a video sweep. Since the spectrum analyser displays only the *spectrum* of the transmitter output it is unnecessary to synchronise it with the video sweep; it is necessary merely to ensure that the spectrum analyser sweep rate is low compared with the video sweep rate, and to this end a long persistence phosphor is essential on the spectrum analyser display tube. A comparison of the two methods is shown in Fig.4. The video sweep to the transmitter is provided by a simple sweep generator which was initially produced with a sweep at television line rate. This was found to be too fast for the application and the manufacturer was persuaded to provide a modified unit which sweeps at television field rate and has an integral synchronising pulse generator. This alternative equipment has a volume of $0.04m^3$ and weighs only 23 kg, representing savings of 60 per cent and 47 per cent respectively.

For mobile maintenance work an oscilloscope must meet two prime requirements. It must be capable of selecting and displaying television waveforms and must also be used as a general purpose dual-trace instrument with delayed time base.

At the start of the UHF colour television service this could be achieved only by means of two separate units, a dedicated television waveform monitor and a general purpose oscilloscope. A move in the right direction was achieved when a manufacturer produced a plug-in television Y-amplifier module for use with an otherwise general purpose oscilloscope.

Eventually, a manufacturer produced a general-purpose dual-trace oscilloscope which can be triggered from television syncs. This oscilloscope is also aligned during manufacture such that the compensated attenuators at the Y-amplifier input produce the minimum of distortion of television waveforms.

Television video measurements, especially for a colour system, require a wide range of equipment, and in the mobile situation the time taken to set up this equipment and make the necessary interconnections at each site can equal the time required to make the measurements. The video test set, as was mentioned earlier, comprises a range of video generating and measuring equipment packaged into a single unit. With the aid of this and an additional oscilloscope all video measurements, except that of chrominance-luminance delay, can be carried out. Furthermore, by adding connections to and from a chrominance-luminance delay test set, this latter measurement is additionally provided for at the throw of a switch.

Packaged in this way the video test set offers three major advantages:

- i Greater speed of operation since all measuring functions can be selected by means of switches
- ii A 58 per cent reduction in volume and a 20 per cent reduction in weight, as compared with an earlier range of equipment
- iii A 43 per cent reduction in cost.

Hitherto, equipment used for making these same measurements consisted of a pulse-and-bar generator, a greyscale generator, a vectorscope, a linearity filter and processing amplifier, as separate items. A comparison of the physical sizes and complexity of the two sets of equipment is shown in Fig.5.

The video measuring equipment and demodulator provided for testing the performance of transmitters can be readily extended to transposers by using a test modulator. However, a further test signal required when dealing with transposers is the standard three-tone test signal for measuring intermodulation products. Basically, this could be done with the aid of three signal generators provided that one of these can be modulated from an external source. Although this solution would require only commercially available equipment, it would take a long time to set up. On each site the output of the three generators would need to be combined in a resistive network. Further, the level and frequency of each generator would have to be adjusted for the appropriate channel and, when externally modulating using video signals, the modulation level would need resetting each time the video test signal were changed to re-establish the correct mean level.

To overcome these problems a test modulator has been developed by the IBA. A block diagram of this is given in Fig.6. This modulator consists of three crystal controlled oscillators of which one, providing the vision carrier, can be modulated. The oscillators operate at intermediate frequency and their outputs are combined in a resistive mixer. The IF signals are converted to UHF in a converter module containing an

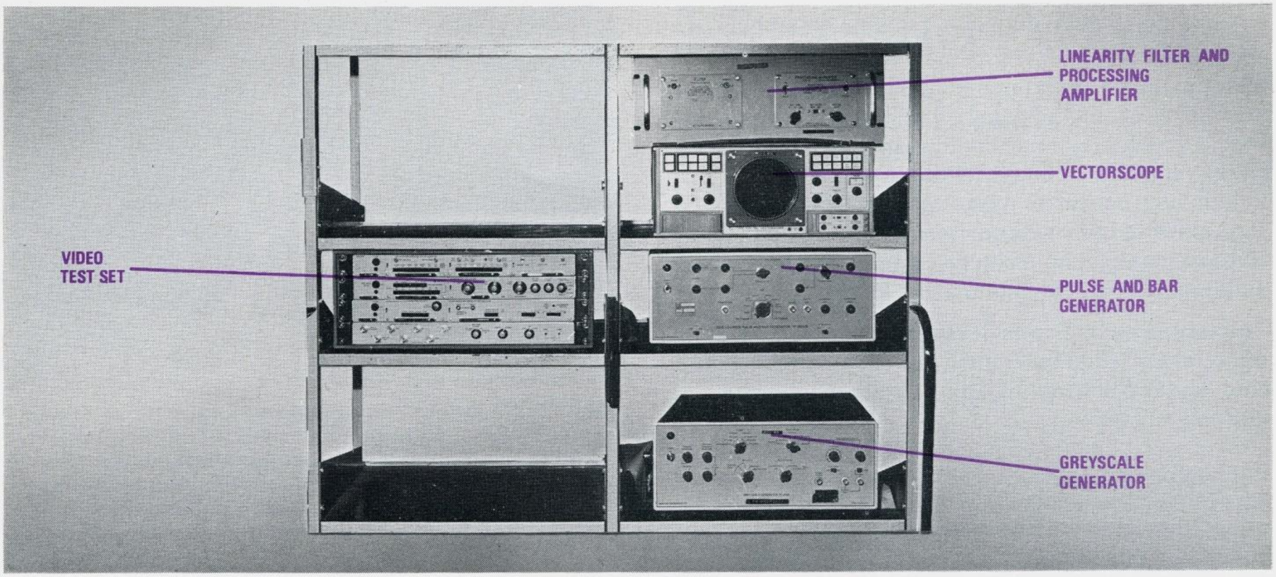


Fig.5. The video test set, for which the block diagram is given in Fig.3, is shown here on the left of the photograph and supersedes all the equipment shown on the right-hand side.

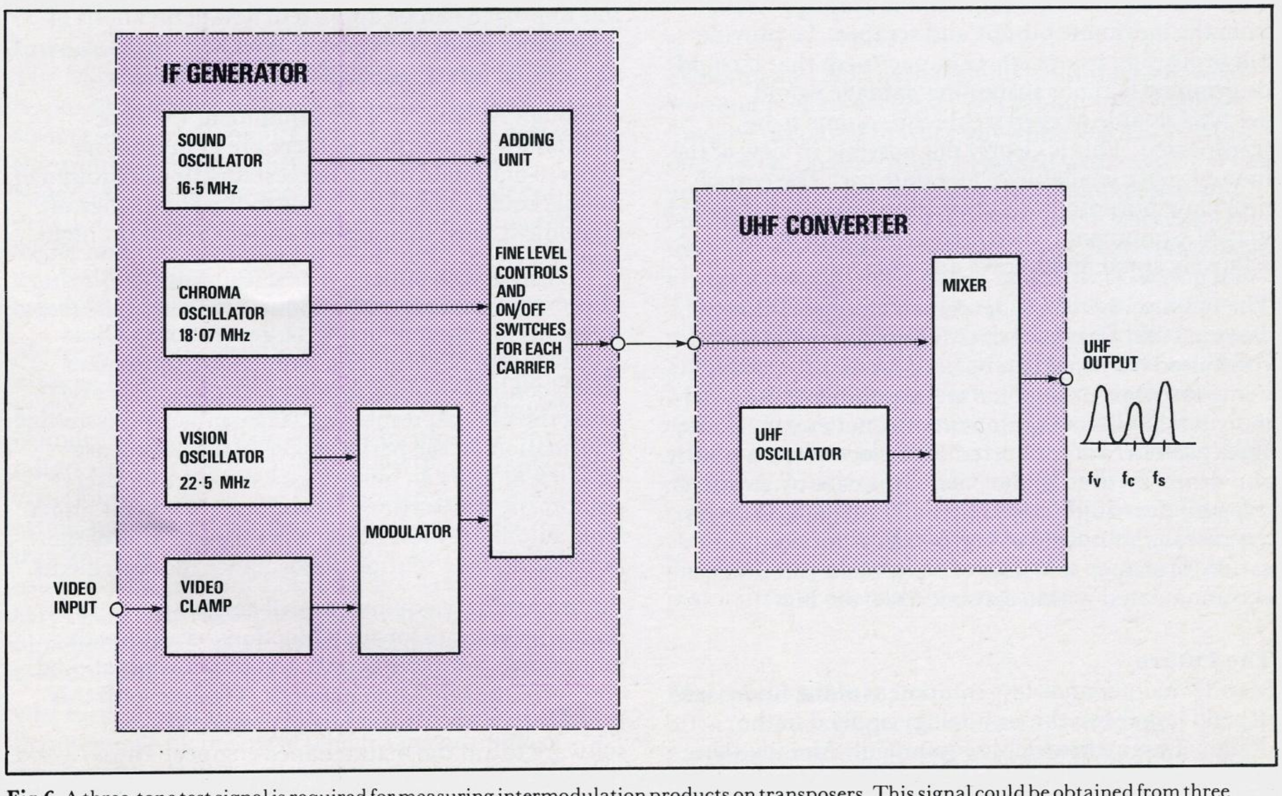


Fig.6. A three-tone test signal is required for measuring intermodulation products on transposers. This signal could be obtained from three separate UHF signal generators, but to reduce the time taken in setting up the oscillators on each site, and also to reduce the cost and volume, a purpose-built test modulator has been developed by the IBA. To extend the equipment for video testing of transposers, the vision carrier can be modulated. The unit can generate signals on any channel in Bands IV and V by changing the UHF converter module. Storage space for four such modules is available in the modulator.

oscillator and mixer. The converter module must be changed for each UHF channel required but, because a team generally works in an area where many transposers are fed from one main transmitter and are, therefore, on the same input channel, this is not such a problem as might at first appear. Nevertheless, the test modulator does include storage space for up to four such converter modules. Moreover, video signals fed to the vision carrier modulator are clamped so that the vision test signal may be changed without affecting the modulation level.

The test modulator was developed to meet a specific requirement and represents considerable savings in cost, size and setting-up time compared with the alternative solution.

Packaging

The test equipment described above spends roughly 75 per cent of its time in an estate car and travels on average 20,000 miles per year. It is unloaded from the estate car, set up on site and loaded back in the vehicle almost every day. This is a somewhat hostile environment and the equipment must be protected from the inevitable bumps and scrapes. To provide full protection from high-G impact such that it could be dropped without sustaining damage would possibly double or even treble the volume to be transported. This is clearly not possible in view of the limited space available in an estate car. The cost of providing purpose-built protection separately for each item of equipment is also high on account of the relatively small numbers of any one item.

The IBA has, therefore, developed a range of transit cases in eight standard sizes. These are made from vulcanised fibre and can be used for all the various items of mobile or regional test equipment. Because individual items of equipment may not exactly fit the cases each item is supported on a piece of foam plastic and firmly secured to the base of the case by straps. In this way the equipment is virtually suspended within the case without need of surrounding packing. A variety of shapes and sizes of equipment can thus be accommodated within any one case, see Fig.7.

Fig.7. Test equipment must be protected when in transit. Specially designed transit cases for each item would be both expensive and inflexible to changes of inventory. A range of eight standard sizes of vulcanised fibre cases has solved this problem. Each instrument is strapped to the base of a case, which does not have to be an exact fit, and a protective cover is fitted over as shown in the photograph.

The Future

Mobile maintenance test equipment of the future will depend largely on the technology applied to the design of future broadcast equipment. Already the IBA operates some 50 television transposer stations in the power range of 2 to 10 W which require no test equipment for on-site maintenance. This type of transposer has sufficient 'built-in' test facilities for tracing faults down to module level, faulty modules then being replaced and repaired at a central workshop. It is hoped that, in the very near future, this approach can be applied to new generations of equipment up to 50 W power level and, in the foreseeable future, up to 200 W power level.

Although Automatic Test Equipment (ATE) is continually under review, there are at present no plans to automate any of the test functions required of mobile equipment. This is due to the wide range of equipment to be maintained and the resultant high cost of ATE.

However, automatic test systems are being introduced as on-site equipment on the larger stations. These take the form of automatic monitoring equipment which continually measure various parameters by using the interval test signal. They provide day-to-day information on the performance of the broadcast equipment and can initiate a switch-over to reserve equipment if distortions exceed certain pre-set limits. This automatic monitoring will relieve teams of the need for making routine performance measurements.

Future ancillary equipment will employ advanced digital techniques for such functions as automatic monitoring, adaptive aerials and remote operational control of the television network. The aim with this type of equipment would be to provide self-test software to aid the maintenance engineer and so avoid the need for providing costly digital test equipment.

MORRIS NEIL KYFFIN, BSC, CENG, joined the Authority in 1967 from the Marconi Company Limited where he had been working initially on the installation of television broadcasting transmitters and later on the development of high-power UHF combining units and transmitting aerial systems. Since joining the Authority, he has been responsible for the maintenance of all aerial and combining unit systems operated by the IBA.

Mast and Aerial Maintenance

by M N Kyffin

Synopsis
Aerials, support structures and combining systems for the IBA's VHF and UHF television, and VHF and MF local radio services, are spread throughout the United Kingdom. They are constantly exposed to the elements and require regular inspection and maintenance.

Expert attention is administered by a group of engineers and fitters who are located within the four regions. The provision of mobile mechanical workshops and the use of specialised electronic measuring equipment, together with an efficient and centralised system for ensuring that spare components are readily accessible, provide the vital insurance against long and costly breakdowns.

Introduction

The Mast and Aerial Maintenance Group is responsible for the maintenance of all support structures, aerials and RF transmission line systems at transmitting stations throughout the United Kingdom, to existing specifications and codes of practice. It is also responsible for maintaining the feeder and the combining systems used within the transmitter buildings, which include sound-vision combining units and 4-channel combining units.

Many designs of aerial support structure are in use ranging from 150 ft self-supporting towers, employed at low-power relay stations, to the 1,265 ft stayed cylindrical mast at Belmont in Lincolnshire, the tallest structure in the British Isles. The complement of aerial types employed is too varied to list in this article but may be divided into VHF and UHF transmitting and receiving aerials, and MF radiators used for Independent Local Radio. Many of the MF aerials are multi-mast arrays which provide a directional coverage. Further information on these is available in *IBA Technical Review 5*.

The system used is one of planned and preventive maintenance by means of which a programme of inspections, electrical measurements and periodic re-furbishing ensures that system faults and the consequent loss of service are kept at a minimum.

Staff are divided between the four engineering regions – South, Central England and Wales, North, and Scotland and Northern Ireland – but inter-regional working is often necessary so that any staff member must be prepared to work anywhere in the UK. Mast and Aerial Engineers are provided with estate cars and are responsible for the transport, maintenance and operation of specialised test equipment necessary for their work. Aerial Technicians and Chief Mast/Aerial Fitters use long wheel-base Land Rovers having four-wheel drive facility, this being necessary for access to relay stations where approach roads are often unmade and/or of steep gradient. Land Rovers used by Chief Mast/Aerial Fitters also tow a power winch and associated erection equipment for installing a temporary chair lift on structures when working aloft. Aerial Technicians include among their responsibilities the transporting and provisioning of aerial spares and general hardware for maintenance projects; they also tow the workshop caravan and maintain and operate its equipment.

Masts and Aerials

Structures are inspected at least twice a year, particular attention being paid to welded joints, the tightness of bolts and fixings and the condition of paintwork and stay grease. The appearance of a suspect weld or fatigue crack would be followed by non-destructive tests which indicate the full extent of the damage and enable remedial action to be taken. If

undetected, such faults could have distastrous results, leading to the possible collapse of the structure.

The tensions of steel guy wires are checked, and if necessary adjusted, once every three years. The guy wires are recoated with grease and the structures repainted every five years, these activities being carried out by sub-contractors. Engineers within the Group prepare the specifications, issue contracts for work and ensure that the projects are supervised and accepted by IBA staff on completion.

All aerials and cables on any structure are examined at the same time as the mast is inspected. Primary consideration is given to the condition of distribution feeders, connectors, and the aerial elements. Owing to the unavoidable use of dissimilar metals, corrosion is an ever-present threat to the satisfactory operation of aerial systems, especially at coastal sites or in areas which suffer a high level of atmospheric pollution.

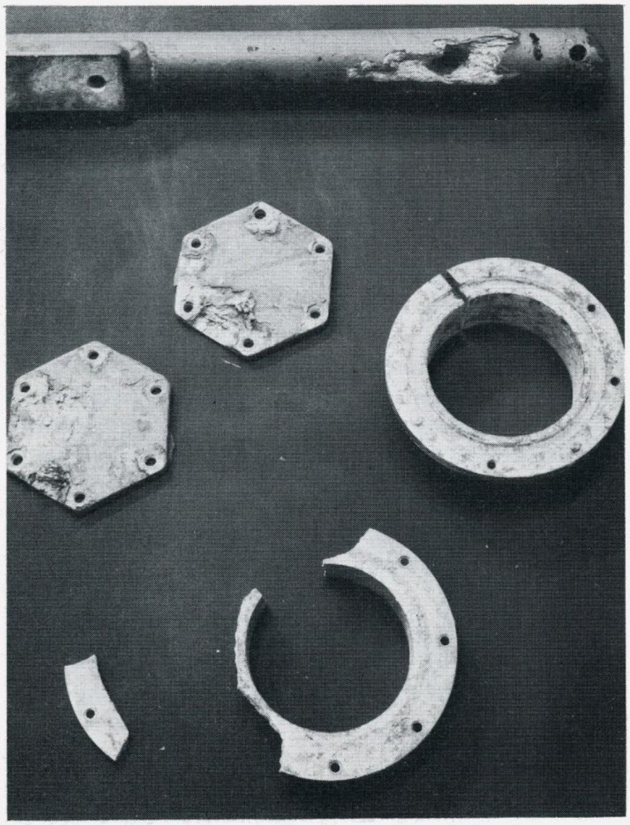


Fig.1. A system of planned and preventive maintenance has been instituted for all the IBA's aerials and support structures. This implies that a regular programme of inspections and tests is carried out by means of which it is hoped that any corrosion, or other defects, can be treated in the early stages. The photograph shows some examples of corrosion that can occur to untreated aluminium components in an exposed environment.

Some examples of this are shown in Fig.1. Early detection of corrosion is imperative so that corrective action can be undertaken thus avoiding costly replacement of components, and the loss of service which the eventual failure of the system would involve.

Routine electrical measurements of the performance of aerial and feeder systems provide a check on their quality. Any deviation from previous records of performance is investigated to determine the underlying cause. Whereas corrosive deterioration is visually apparent, electrical measurements can be interpreted to indicate the location of internal components damaged by burning and arcing, or which have become loosened by the action of wind and temperature. The refurbishing of aerial systems takes place on summer days before the start of transmission. The priority of work is decided as a result of inspection or by the length of time since a previous major overhaul was undertaken. In general an aerial is thoroughly overhauled once very five years.

The procedure adopted during an overhaul is, first, to dismantle all interconnections between distribution components to check their electrical quality, and second, to treat the connection against deterioration by corrosion before reassembly. This treatment consists of coating the mating surfaces and associated nuts and bolts with an inhibiting paste having a zinc chromate base, then replacing the sealing rings and repainting on reassembly. When treated in this way, aerial systems in the worst of environments will survive for five years with a minimum of deterioration.

Corrective maintenance has to be undertaken in the event of a failure. As such a failure involves reduction in the power radiated by a station, the staff concerned are called upon to take instant remedial action, often in difficult weather conditions. The speedy rectification of a fault usually depends on having ready access to spare components covering all equipment in operation. This requirement is met by the holding of spares in IBA Central Stores at Alperton in London. The Group's engineers liaise with the staff at Central Stores and are responsible for ensuring that the holding of spares is properly updated, especially as regards new types of equipment, and that individual items are correctly identified and labelled.

It is vital that, in the event of a total structural collapse, the service be restored in the shortest possible time, using emergency equipment. For this purpose a 250 ft 'zip-up' mast and two pole-mounted aerials are available for use in a VHF situation

whereas, in a UHF case, a 650 ft spare mast and appropriate aerial can be erected in collaboration with the BBC.

Transmitter Combining Units and Allied Systems

The separate sound and vision outputs of the IBA transmitters at a television station are first combined. Then, in the case of UHF transmitters, which are all co-sited with BBC transmitters, it is usual for a single feeder carrying the IBA output signal to be connected as one input of a 4-channel combining system, the other inputs being signals representing BBC1, BBC2 and possibly, in the future, a fourth television programme.

The combined output from all these sources is then fed to the two halves of the transmitting aerial. The performance of these combining units and associated components is checked annually. The same applies to the sampling probes, and their alignment, as these not only monitor the reflected power but also protect the aerial equipment against a breakdown in the combining unit/feeder system.

The failure of feeder components within transmitter systems is usually associated with overheating. Replacing such components is basically a mechanical problem, but it usually necessitates a realignment of the system before transmission is resumed, and the responsibility for both the repair and the realignment falls on the engineers of the Mast and Aerial Group.

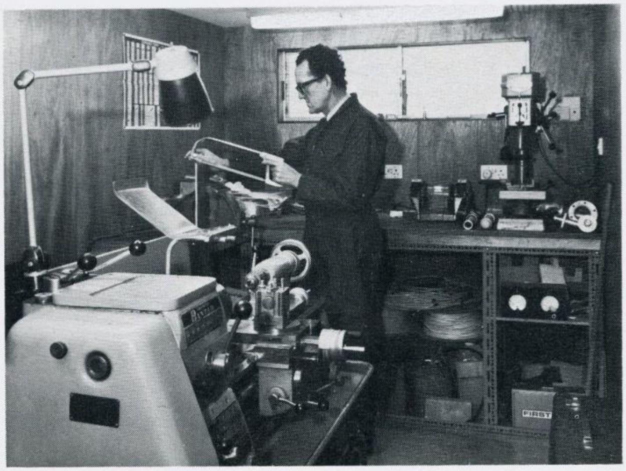
Test Equipment

The measurement and alignment of aerial and combining unit systems demands the use of very specialised test equipment. The complement of this equipment must be such as to allow fast, accurate measurement, yet be portable enough to allow the complete system to be carried in an estate car, see Fig.2. The system adopted is based on an oscilloscope used with the following range of modules:

1. Sweep Frequency Analyser System – used in conjunction with a sweep frequency voltage generator for measuring through-loss parameters within a 60 dB dynamic range, or in conjunction with directional couplers to measure return loss within a 40 dB dynamic range.
2. Time Domain Reflectometer – used to determine the quality of a cable by applying to it a step waveform of fast rise-time. Any discontinuity will produce an echo on the screen of the oscilloscope which, if suitably analysed, can yield an accurate indication of the magnitude and position of the fault.

Fig.2. A complement of specialised test equipment is needed for the measurement and alignment of aerials and combining unit systems. This must also be sufficiently compact and portable to be stowed in an Estate type vehicle as shown.

Figs.3(a) and (b). Exterior and interior views of the 18 ft caravan used as a mobile workshop. In remote areas where no workshop is available this is essential for the refurbishing of components and for manufacturing replacement items. It is towed by a long wheel-base Land Rover.



3. Vertical Amplifier and Time Base – provides a normal oscilloscope facility, useful when repairing test equipment and other electronic equipment.
4. Spectrum Analyser – necessary for identifying interfering signals, this module determines the magnitude and frequency of any signal from 1.5 MHz to 1.5 GHz, and also allows the accurate measurement of the input RF signals to UHF local relay stations.
5. Polaroid Camera – to photograph waveforms from the screen of an oscilloscope. The photographs are then available for photocopying and distribution.

Other equipment includes a vectorscope, battery operated field strength meters and a demountable telescopic mast with proprietary aerials. There is a mobile workshop for use at remote stations where no workshop facilities are available. It comprises an 18 ft-long caravan equipped with a 6″ lathe, vertical drill, bench grinder, workbench and all necessary engineering tools, Figs. 3 (a) and 3 (b). A power-driven winch and associated equipment are also available and can be towed by a long wheel-base Land Rover and used for installing a temporary chair lift on structures during maintenance. This is shown in Fig.4.

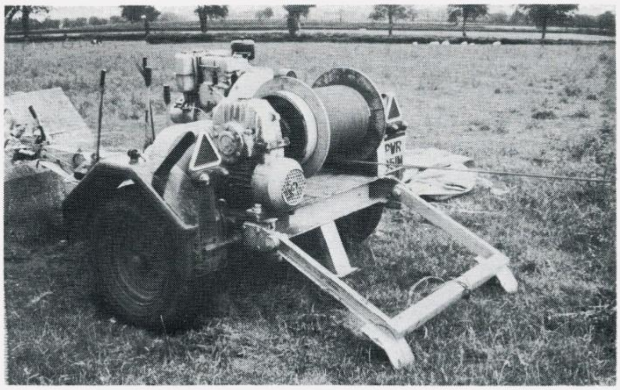


Fig.4. A portable power-driven winch is used in conjunction with a temporary chair lift when carrying out maintenance work aloft. It is used both for hoisting men and materials.

GARTH LAWLEY came to the Authority as an engineer at the Lichfield transmitting station in 1957, having previously served in the Royal Air Force and been employed by the Post Office. He became Senior Shift Engineer at Burnhope in 1961 and later at Lichfield. Since 1970, when he was appointed Senior Engineer on the staff of Regional Engineer, Midlands, he has been occupied with the commissioning and maintenance of both radio and television stations within the region. He is married with four children and his hobby is gliding.

System Performance of Tandem Television Transmitter Chains

by G Lawley

Synopsis
Most of the television transmitting stations carrying the IBA's UHF service receive their signals over-air from another transmitter and in some areas, particularly in hilly terrain, this can lead to a number of transmitters, or transposers, being fed in tandem. Special precautions must, therefore, be taken if the additive effect of the various types of distortion that can occur at each stage in the transmission chain is not to exceed the maximum permissible amount.

In some cases, performance can vary with changes in the weather or season and, where an over-sea path is involved, the state of the tide as well. Hence, any assessment of performance has to be made not merely from a single set of readings but from a number recorded over a period of time.

Of the different types of distortion to which rebroadcast links are especially prone, the most significant are quadrature distortion, amplitude-frequency distortion, noise, interference and the distortion due to echoes. The methods of dealing with each of these are described in turn.

Introduction

Of all the transmitters that constitute the IBA's UHF network, only sixteen are directly connected to the programme sources by video or microwave link. Coverage is then further extended by transmitter or transposer stations which receive their input signals over-air. Fig.1 shows part of the network serving Central England where each satellite station obtains its input signal from Sutton Coldfield. In other parts of the network tandem chains of transmitting stations have been built, and as the network continues to expand more of these will come into operation. Fig.2 shows part of the network in South Wales where a chain of transmitting stations is used.

The reception and retransmission of the off-air signals used in the network present various problems to the broadcasting engineer if the accumulated distortions are to be kept to a minimum. The different forms of signal distortion which can result from rebroadcasting may be listed as follows:

1. Quadrature distortion.
2. Amplitude-frequency distortion.
3. Noise.
4. Interference.
5. Distortion due to echoes, etc.

Each of these will now be considered.

Quadrature Distortion

Arising from any transmission standards which specify negative modulation and vestigial sideband transmission, inherent system distortion is produced when envelope receivers are used to feed satellite transmitters. This distortion mostly affects highly saturated colours having a large luminance level, such as yellow, but all parts of the signal are affected in varying degrees, depending on the modulation depth.

Originally all satellite transmitters were equipped with envelope detection receivers to provide their

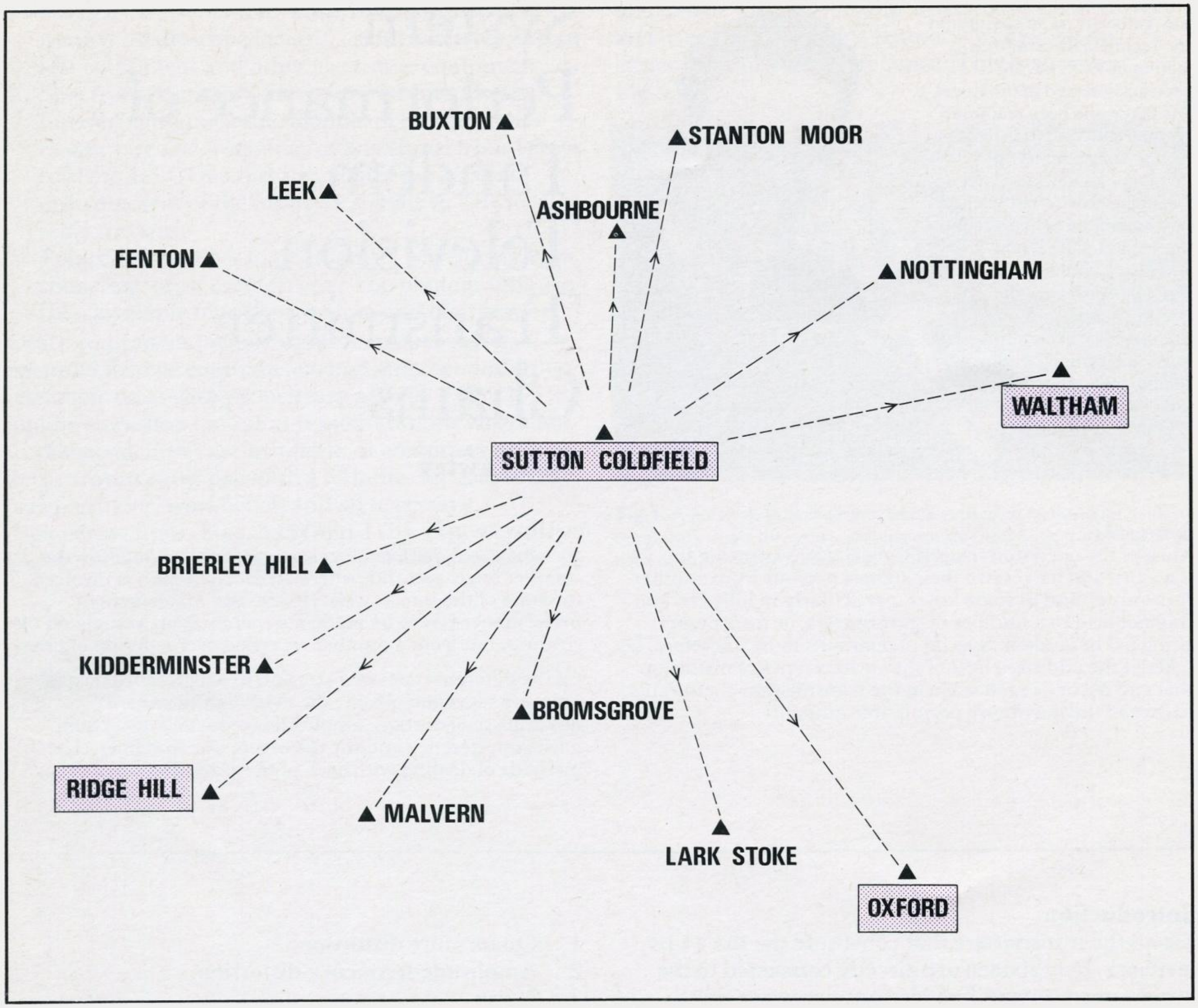


Fig.1. The great majority of the IBA's UHF transmitting stations receive their vision and sound input signals over-air from another transmitter, or even a series of transmitters. This diagram illustrates that part of the network serving Central England. The signals from the Studio Centre in Birmingham are sent to the central transmitter at Sutton Coldfield; the vision by microwave link, the programme sound by line. They are then received off-air at the three main stations, Oxford, Waltham and Ridge Hill, and at the eleven transposer stations as shown.

input vision and sound signals. Fig.3 shows the effect of quadrature distortion on colour bars and illustrates why it would be undesirable to use more than one envelope receiver in any chain of transmitter stations. Receivers having synchronous detection, which introduce no quadrature distortion, have been developed recently by the IBA. By using synchronous receivers, chains of transmitters producing no inherent distortion, are now possible.

Consequently, the IBA's transmission network is being converted to the use of receivers employing synchronous detection, thus completely eliminating quadrature distortion effects from the transmitted signals.

Amplitude-frequency Distortion

The signals received off-air from a parent station can be affected by the summation of the limits as specified for the combining units at the parent station, the transmitting aerial system, the receiver aerial system and 4-channel splitter (if used) at the satellite station, as well as by topographical and climatic conditions.

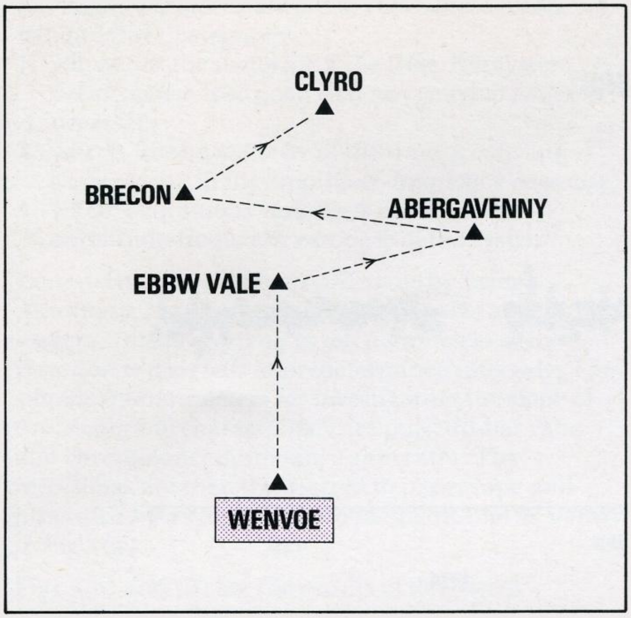


Fig.2. Incoming vision and sound signals to the main station at Wenvoe, in South Wales, arrive by cable. The four transposer stations constitute a tandem chain and each receives its input signals off-air from the preceding station.

In the steady state, one common cause of distortion is for a slope to occur in the amplitude-frequency characteristic over the pass-band. This, in time domain terms, has the effect of altering the pulse-to-bar ratios and chrominance-luminance gain ratios on the test signals used for monitoring the performance.

When an off-air fed station is constructed, system measurements are necessary to evaluate the transmission chain. The measuring of these systems has been found difficult due to changes in performance that can occur with changes in weather, tides, etc. A single set of figures may not indicate the true position; to obtain a more complete knowledge of the performance of a chain, long-term recordings are necessary. Long-term measurements carried out by

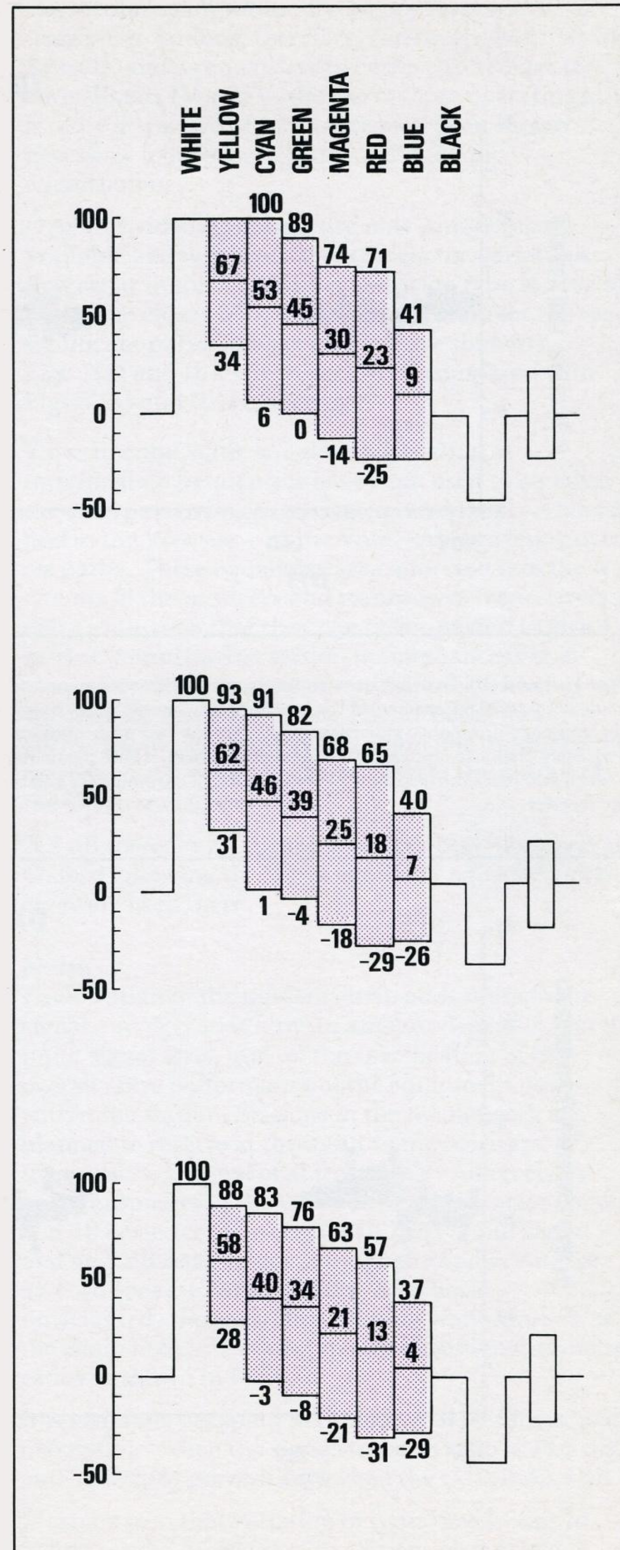
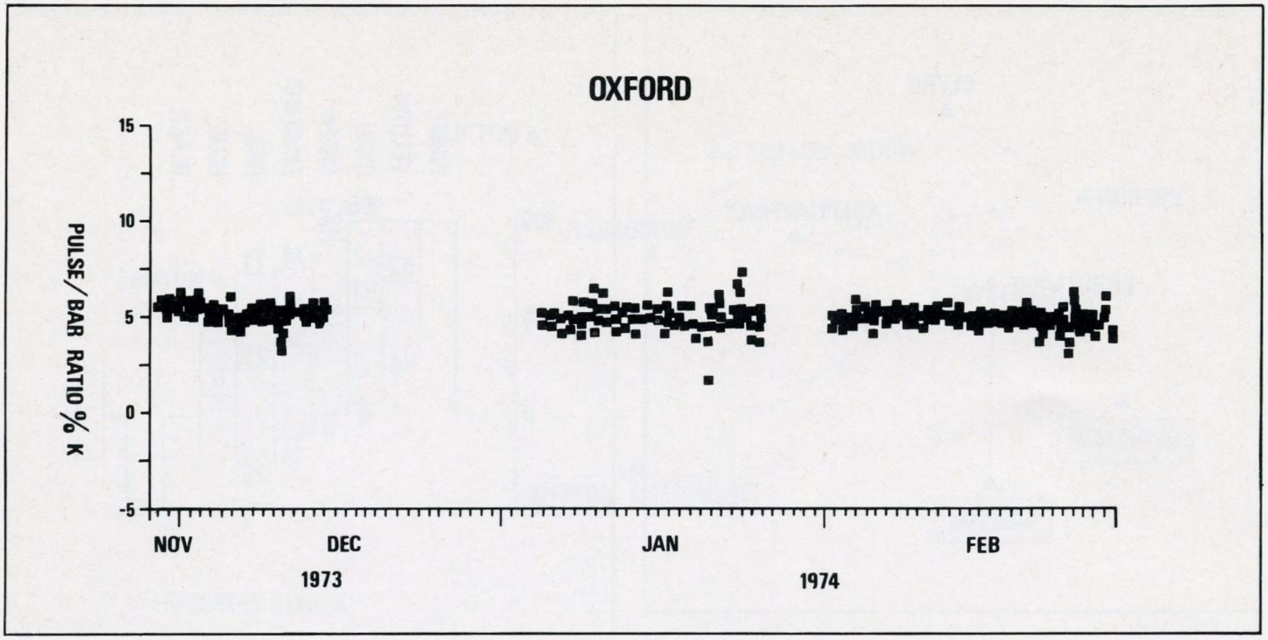
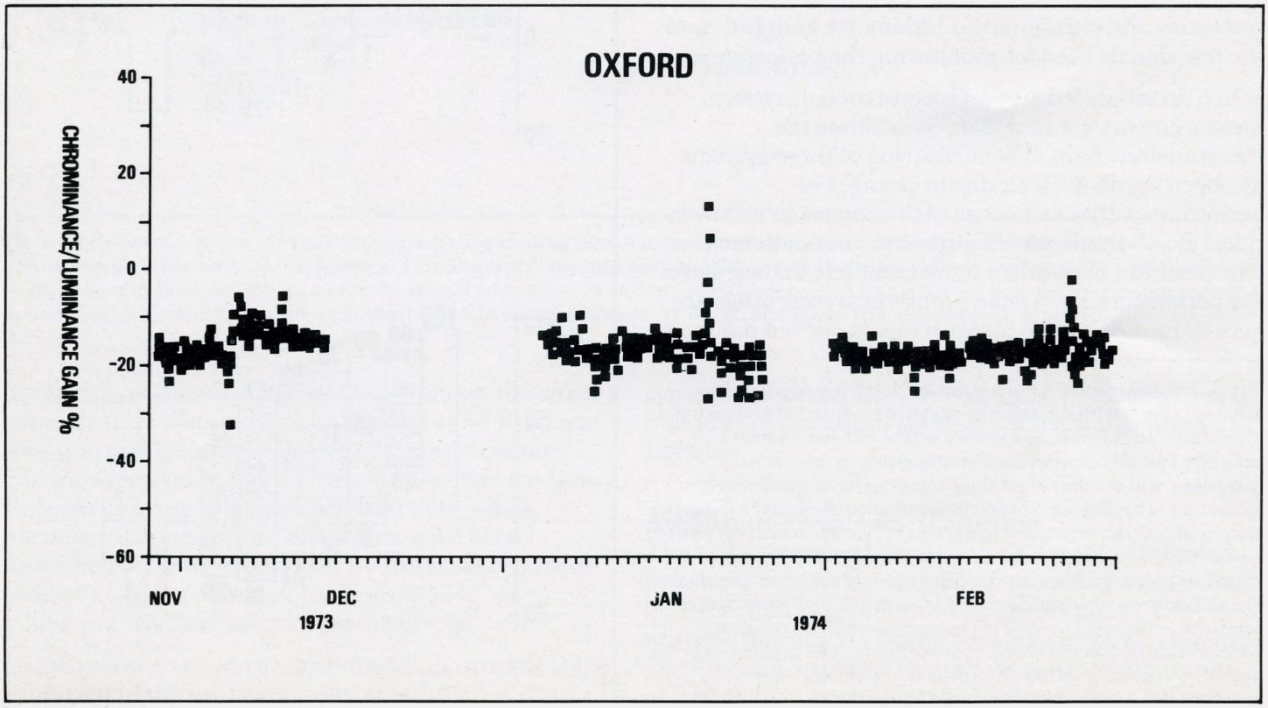


Fig.3. The use of envelope detection for receiving signals which have to comply with the needs of negative modulation and vestigial sideband transmission, as specified by the 625-line System I employed for all UHF television broadcasting in the United Kingdom, will inherently produce some degree of quadrature distortion. The diagram shows the luminance levels and sub-carrier amplitudes at different parts of the EBU colour bar waveform as used by the IBA (shown at the top) and how these are affected by quadrature errors. After envelope detection at a receiver terminal, the waveform is typically distorted as shown in the centre figure, whilst after a second process of transmission and reception it is further distorted as shown in the lower figure. The problem is being solved by replacing all envelope detection receivers with synchronous demodulators designed by the IBA.



Figs.4(a) and (b). In order to evaluate the performance of an unattended off-air fed station or transmission chain, long-term recordings are made of up to 10 parameters of the insertion test signals. After being processed by a computer the results for pulse-to-bar ratio and chrominance-luminance gain ratio, which are the two most significant parameters for investigating irregularities in the amplitude-frequency response, appear in the form shown here. These particular results were taken on the over-air path between Sutton Coldfield and Oxford and reveal a consistent 2 dB reduction of chrominance relative to luminance caused partly as a result of envelope detection used in the receiver.



IBA engineers have shown that rebroadcast links can fall into three categories:

1. where, for the majority of the time, the system performance is so good that no remedial action is necessary;
2. where, for the majority of the time, a constant slope occurs in the amplitude-frequency response;
3. where continuous variations occur in the amplitude-frequency response of the system.

Long-term measurements are made by using Automatic Measuring Equipment (AME) and data loggers which record up to ten parameters of the insertion test signals at predetermined intervals. The significant parameters for investigating the slope of the amplitude characteristic are pulse-to-bar ratio and chrominance-luminance gain ratio. The recordings are then transferred to paper tape and processed by a computer, producing results as shown in Fig.4(a).

Figs.4(a) and (b) are the results of long-term recordings made on the over-air path between Sutton Coldfield and Oxford, and show that there is approximately a 2 dB reduction of chrominance, relative to luminance, on the received signal. The results also show that this degradation is fairly constant. The receiver used at Oxford for these measurements employed envelope detection, which itself contributes 0.5 dB to the overall drop in chrominance.

This type of static slope was encountered also in the Wenvoe – Ebbw Vale – Abergavenny – Brecon – Clyro chain and was found to be due to the addition of slopes occurring in the 4-channel combining and splitter units used at each station and which individually were within design specification. Because each transposer station uses common sound and vision amplification, the sound-to-vision ratio measured at Brecon was –14 dB instead of –7 dB.

An example of continuous variation of amplitude-frequency response is shown in Figs.5(a) and (b), these being the results of recordings made at Arfon which receives Blaen Plwyf off-air to feed Llandonna and Moel-y-Parc with input signals. The variations shown in these results were caused primarily by the over-sea path. This network is shown in Fig.6.

Equalisers for correcting errors in the overall amplitude-frequency response of a system could be made to operate on the carrier at RF, or at an intermediate frequency, or on the signal at baseband.

The use of video correctors is limited to stations using receivers. They cannot be used at transposer stations. Correction of amplitude-frequency response at transposer stations, therefore, can be applied only at RF or IF, and as equalisers to correct at RF have to cover Bands IV and V, the use of those operating at IF is more attractive. It has, moreover, been shown necessary to have both static and dynamic equalisation.

Dynamic video equalisers are now commercially available and will be used to correct the variations that occur in the Blaen-Plwyf to Arfon type of over-air path. The effects of this type of correction for the two significant parameters concerned are shown in Figs.7(a) and (b), which should be compared with Figs.5 (a) and (b) respectively.

Experimental static equalisers operating at intermediate frequencies have been used to equalise the errors occurring in the Sutton Coldfield – Oxford and in the Wenvoe – Ebbw Vale – Abergavenny over-air paths. These equalisers are connected into the IF circuits of the receivers and transposers respectively as extra units such that they can be by-passed to give a level response during station maintenance. Fig.8 shows a typical response of a transposer with and without the corrector fitted. The fitting of these correctors in the South Wales chain has produced the correct –7 dB sound-to-vision ratio at the output of the Clyro transposer.

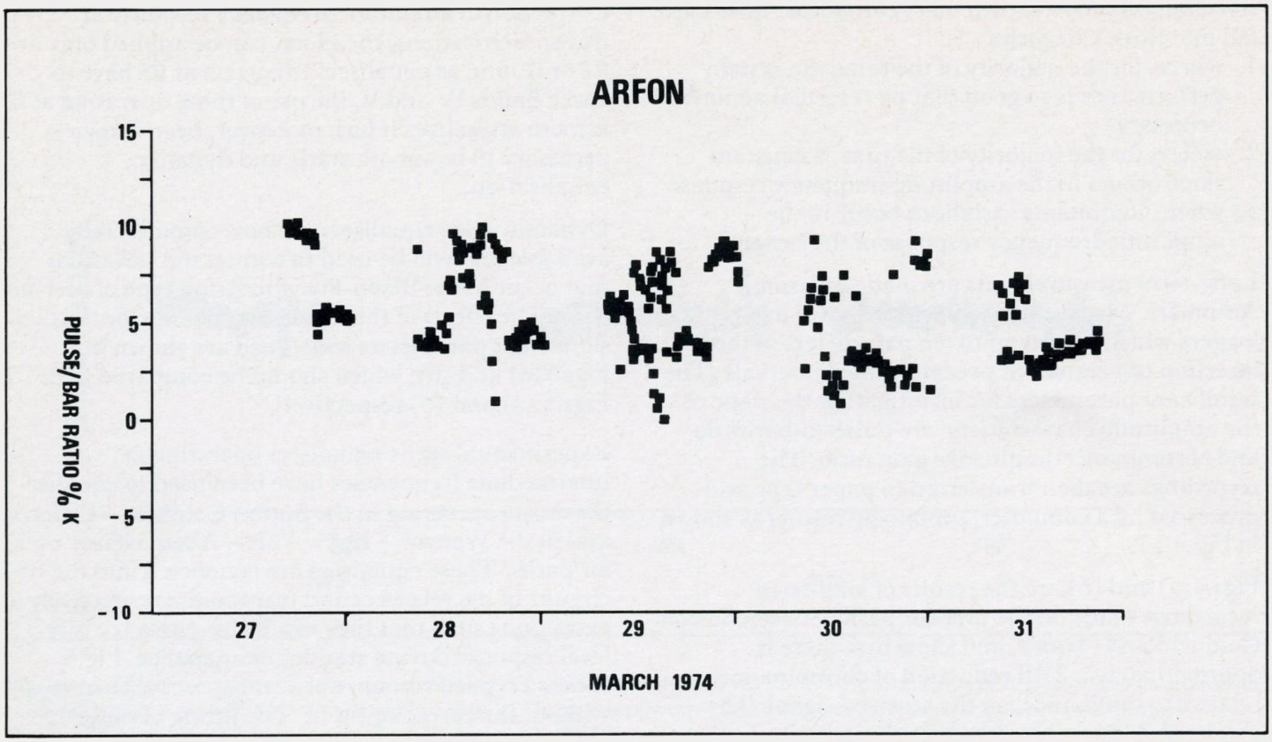
A 2 dB increase in chrominance has been obtained at Oxford following the use of similar IF equalisers in the receivers used there.

Noise

Each station in the tandem chain adds noise to the signal and degrades it by an amount depending on the input signal level, and on the specification of the overall noise performance of the equipment used within the station. Stations in the IBA network are planned to receive at the input to the receivers, or transposers, a signal of at least 2 mV. All receivers and transposers in the UHF network have noise factors of 8 dB or better. The result of a 2 mV input signal and an 8 dB noise factor is a signal-to-noise ratio of 49.6 dB (peak-to-peak picture/RMS noise – unweighted). Four tandem satellite stations, such as the chain in South Wales, should have signal-to-noise ratios as shown in Fig.9.

It is generally accepted that noise on a picture is 'just perceptible' when the signal-to-noise ratio is 38.5 dB, and 'definitely perceptible' when the ratio is 32.5 dB.

It can be seen that variation of signal levels, due to fading caused by weather conditions, can produce


ARFON
15
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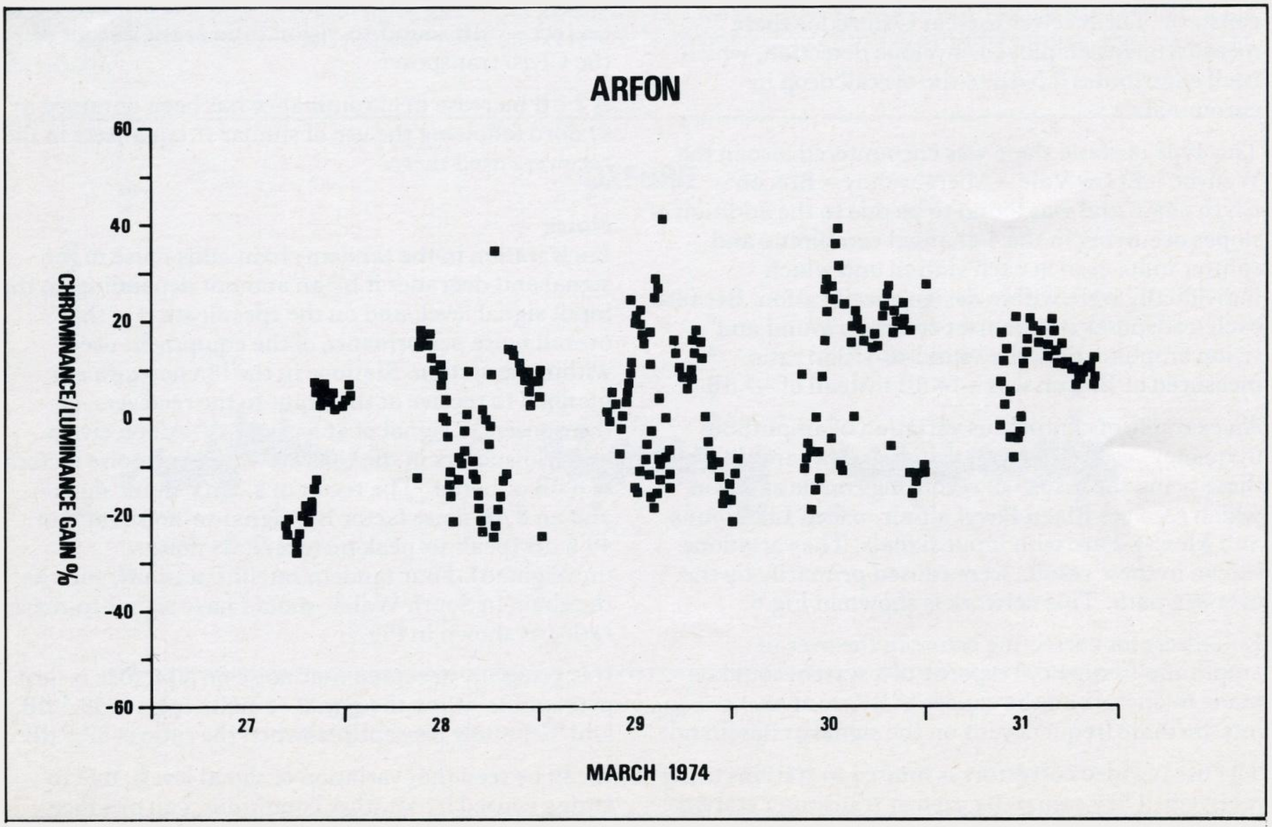
ARFON
60
40
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0
-20
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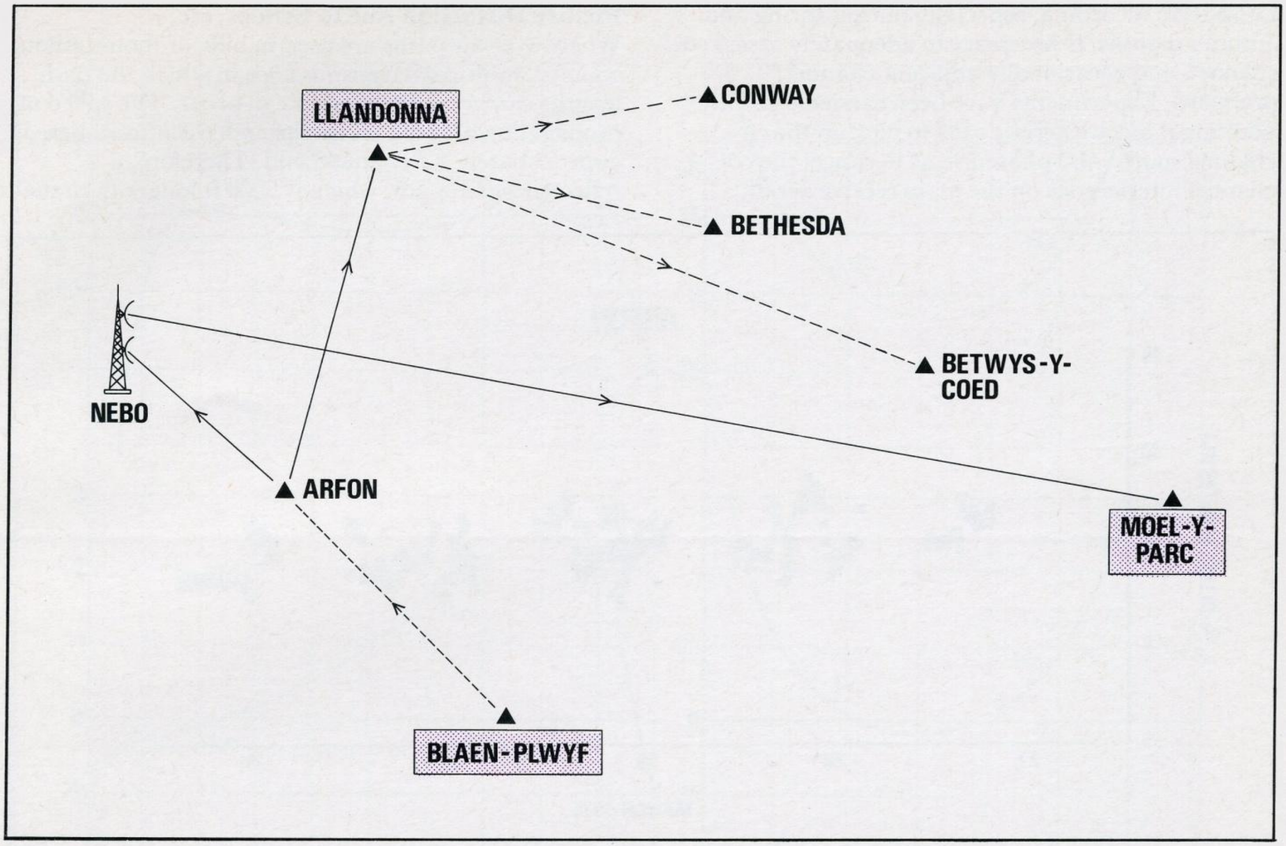


Fig.6. The network of transmitters in North Wales. Signals at Arfon are received off-air from Blaen-Plwyf and are then sent by microwave links to Llandonna and, via a link station at Nebo, to Moel-y-Parc. From Llandonna there are three further off-air links to Conway, Bethesda and Betwys-y-Coed.

noise effects at the end of long chains of transmitting stations. Signal enhancement which occurs on over-air paths can also cause overloading of input circuits producing intermodulation products which visually resemble noise.

Noise problems in tandem chains have to be investigated by using the long-term recording techniques discussed earlier.

Interference

The UHF television network operates in Bands IV and V which range from 470 – 582 MHz and 614 – 854 MHz respectively. Each station in the network requires a group of four frequency channels to accommodate ITV1, BBC1, BBC2 and a fourth programme as yet unallocated. The four channels have to be spaced sufficiently to prevent significant interference occurring between these different transmissions, all of which emanate from the same site. In practice, this arrangement has resulted in only nine groups of channels being available.

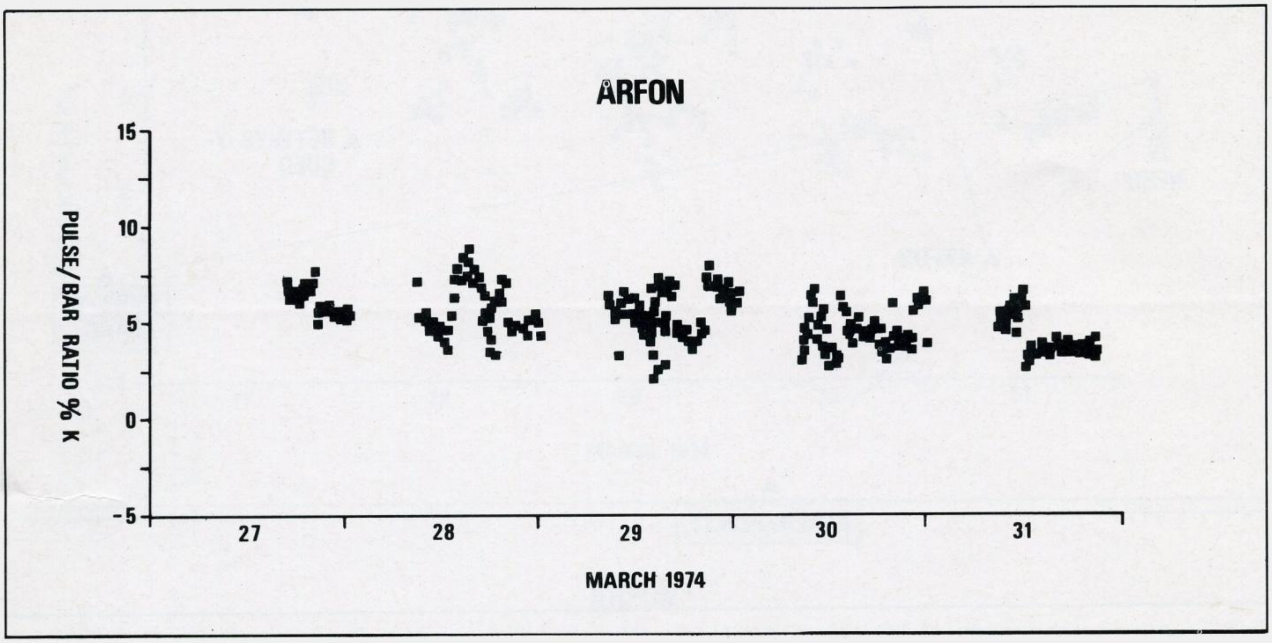
Each station has to be planned so that no significant co-channel interference is experienced by viewers in its service area; and, in the case of a satellite station, the receiving aerial system has to be arranged so that it, too, is not susceptible to co-channel interference. Levels of co-channel interference picked up on a receiving aerial can vary considerably with changes in weather conditions.

Figs.5(a) and (b). In some cases, as when an over-sea path is involved, continuous variations occur in the amplitude-frequency response of the system. One such case is the off-air link across Cardigan Bay from Blaen-Plwyf to Arfon (*see Fig.6*). These recordings, made at Arfon, show the spread of results obtained.

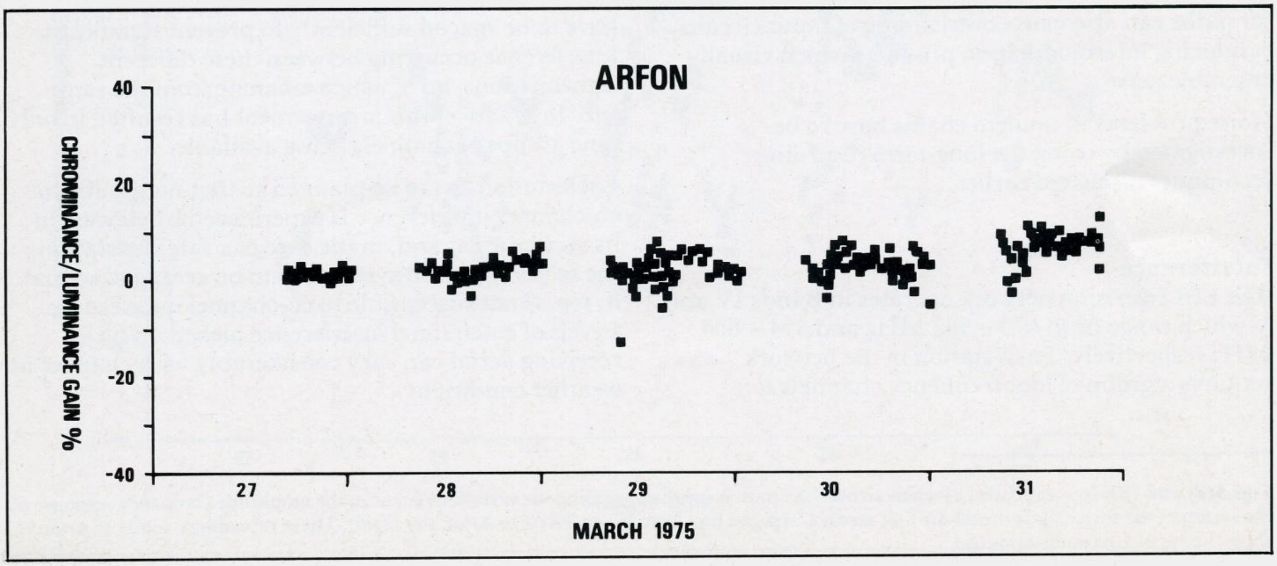
Long-term recording, especially during spring and autumn months, is necessary to adequately assess co-channel, and occasionally adjacent channel, problems. Experiments have been carried out with additional receive aerials used to pick up the co-channel source and phased so as to cancel the co-channel interference on the main receive aerial.

Picture Distortion due to Echoes, etc.

Where over-air paths are used in hilly or mountainous country, multipath transmissions in which the path lengths can be quite different can occur. The speed of propagation of radio waves through the atmosphere is approximately 1 ft/nanosecond. Therefore, a reflected signal path, which is 5000 ft longer than the



Figs.7(a) and (b). The continuous variations in amplitude-frequency response, as exemplified in Figs.5(a) and (b), can be corrected by the use of equalisers. These can be made to operate either on the RF or IF signal, or, at stations using receivers as distinct from transposers, on the video baseband signal. Commercially available dynamic video equalisers were used at Arfon in obtaining the results shown here. Their effect can be seen by comparing these results with those given in Figs.5(a) and (b) which were obtained without equalisation.



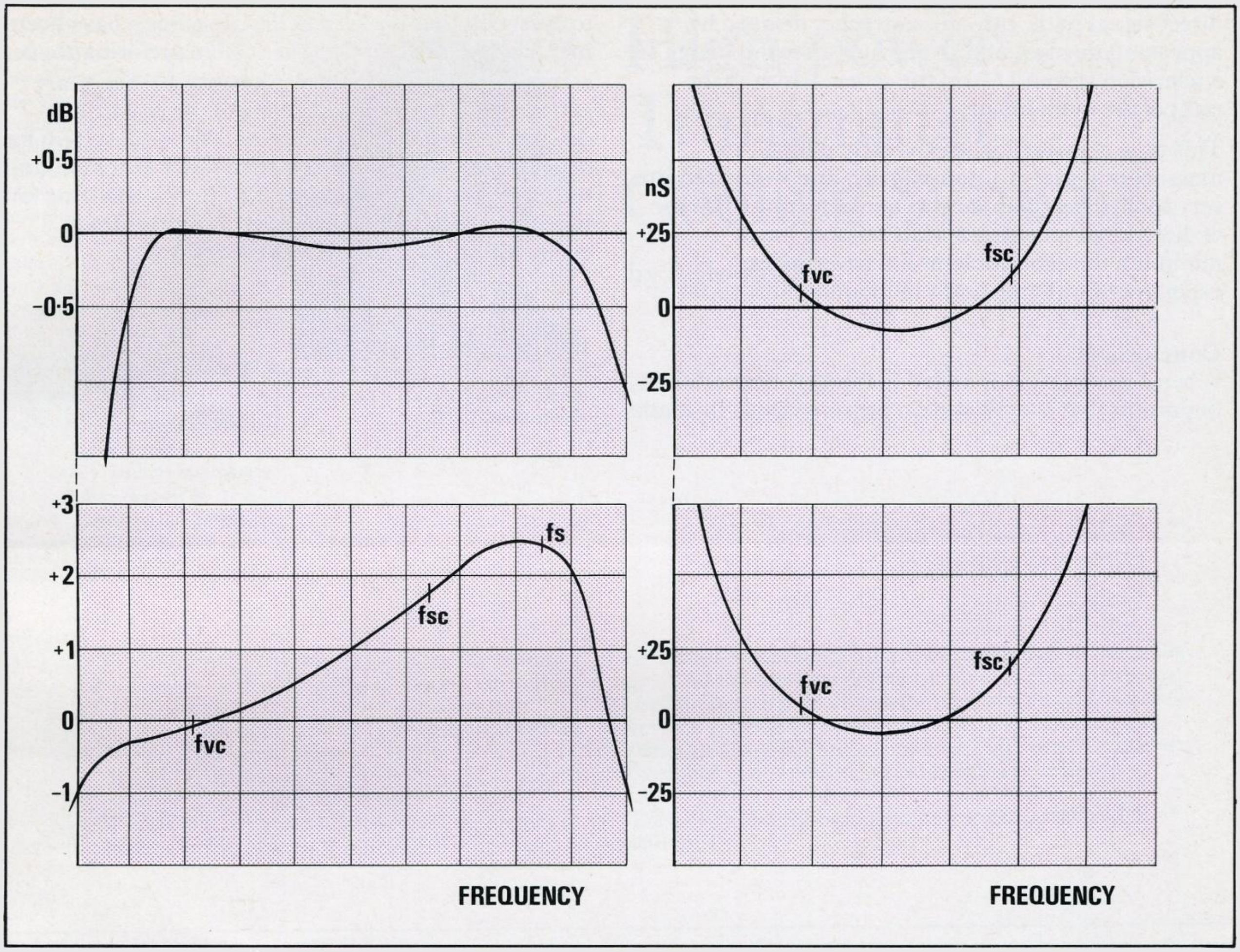


Fig.8. In this diagram the performance, in respect of frequency response and group delay characteristics, of a typical transposer without an experimental fixed IF bandpass corrector (upper curves) is compared with its performance with correction (lower curves). It should be noted that the group delay characteristic is virtually unaffected.

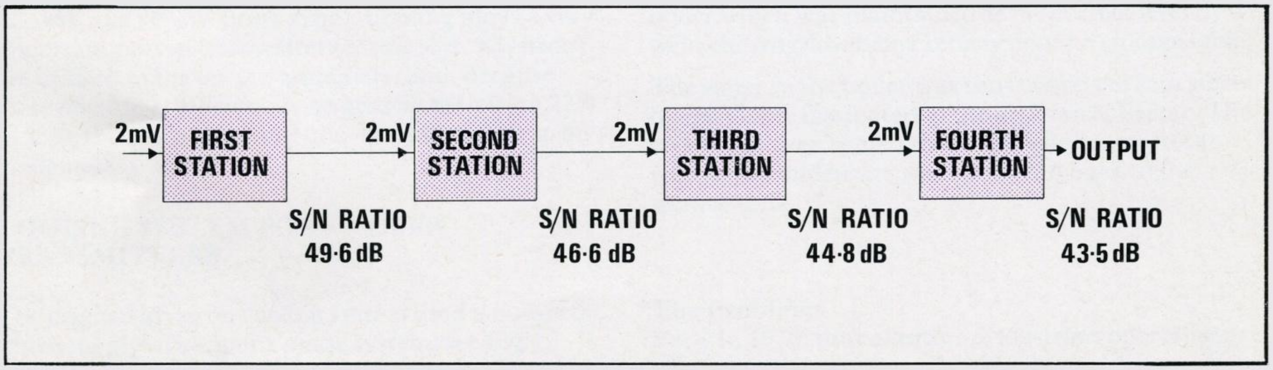


Fig.9. In considering tandem chains, such as in South Wales (Fig.2), it must not be overlooked that each station makes its own contribution to the noise added to the signal. The receivers and transposers used have noise factors of 8 dB or less, and require an input signal of at least 2 mV. The signal-to-noise ratios at successive points in the chain can then be calculated and are as shown in the diagram. Subjectively, noise is generally considered to be 'just perceptible' when the unweighted peak-to-peak signal/RMS noise ratio is 38·5 dB and 'definitely perceptible' if it is 6 dB worse.

direct signal path, can cause an echo, delayed by approximatley 5μs, and so produce a second image on a television screen 1/10 of the screen width to the right of the main image.

This type of distortion is extremely difficult to measure and assess automatically, and would require very sophisticated apparatus for correction. The use of directional receiving aerials reduces it to a minimum though problems are nevertheless experienced on some paths in mountainous country.

Conclusions

When a new station is added to the UHF network it is important that overall system measurements be made to ascertain that the system design criteria have been met. To be confident that the system performance is acceptable, long-term measurements are necessary and remedial action taken if any of the distortions described above are encountered. After the system has been proved satisfactory it is then possible to maintain the tandem chain within specified limits, allowing for the normal slight changes of performance which occur within the transmitters themselves.

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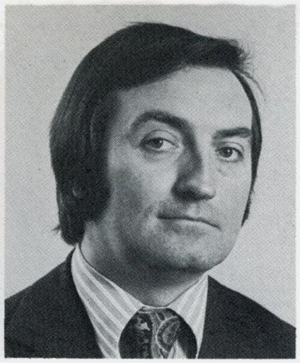
EDDY HOWARTH, MITE, started his career with the General Post Office External Telecommunications Executive, serving on one of their transmitting stations. After joining the Authority in 1961, he spent a total of eight years on transmitting stations as an operations and maintenance engineer. At present he is a Senior Engineer in the Maintenance Section of the Station Operations and Maintenance Department where he is responsible for a group providing support services for VHF transmitters and transposers, UHF transmitters, and for microwave and HF radio links. He is married, has three daughters and lives in Hampshire.



High-power Transmitter Cooling Systems

by E Howarth

Synopsis
The high-power UHF transmitters operated by the IBA use vapour phase cooling. It is well recognised that transmitter cooling systems, especially water cooling systems, can produce difficulties and, true to form, some major problems materialised during their early years in service.

At the lower-power stations, corrosion occurred on the klystron collectors due to the local build-up of impurities in the cooling water, and in solving this problem it became necessary to make extensive modifications. On the higher-powered transmitters deterioration of synthetic rubbers used in the water cooling system caused an unacceptable amount of preventive maintenance, and the systematic replacement of rubber components with others made of a thermoplastic material (PTFE) became necessary.

This article describes in detail these problems and their solutions.

Introduction

The first transmitters installed for the UHF colour service were designed for output powers of between 6 ¼ kW and 40 kW (peak sync). Cooling plays a very important part in transmitters of this sort. Klystrons are utilised in the output amplifiers, and, because these operate at efficiencies no greater than from 22% to 35%, there are large amounts of waste power to be dissipated as heat.

COOLING SYSTEM FOR 6 ¼ /10kW TRANSMITTERS

The original klystron cooling system used a pumped water supply in a vapour phase system, see Fig.1. Vapour phase cooling makes use of the high latent heat of vaporisation of water, i.e. 539 calories/gram. For example, every gram of water at, say, 40°C that is turned into steam removes approximately 600 calories of heat from the collector.

Referring to Fig.1, the water from the storage tank (capacity 35 gallons) was pumped to the klystron boiler which was maintained at the correct level by a weir, the overflow being returned to the storage tank.

The water in the boiler was thus converted into steam by the power dissipated in the klystron collector. The steam was then routed to a steam condenser from which the condensate was circulated back to the storage tank.

The Problems

Early in 1970, the collectors of klystrons operating as vision amplifiers at two of the Authority's transmitting stations exhibited severe corrosion, see Fig.2. This was so severe that in one case it was necessary to burn the collector free from the boiler by means of acid.

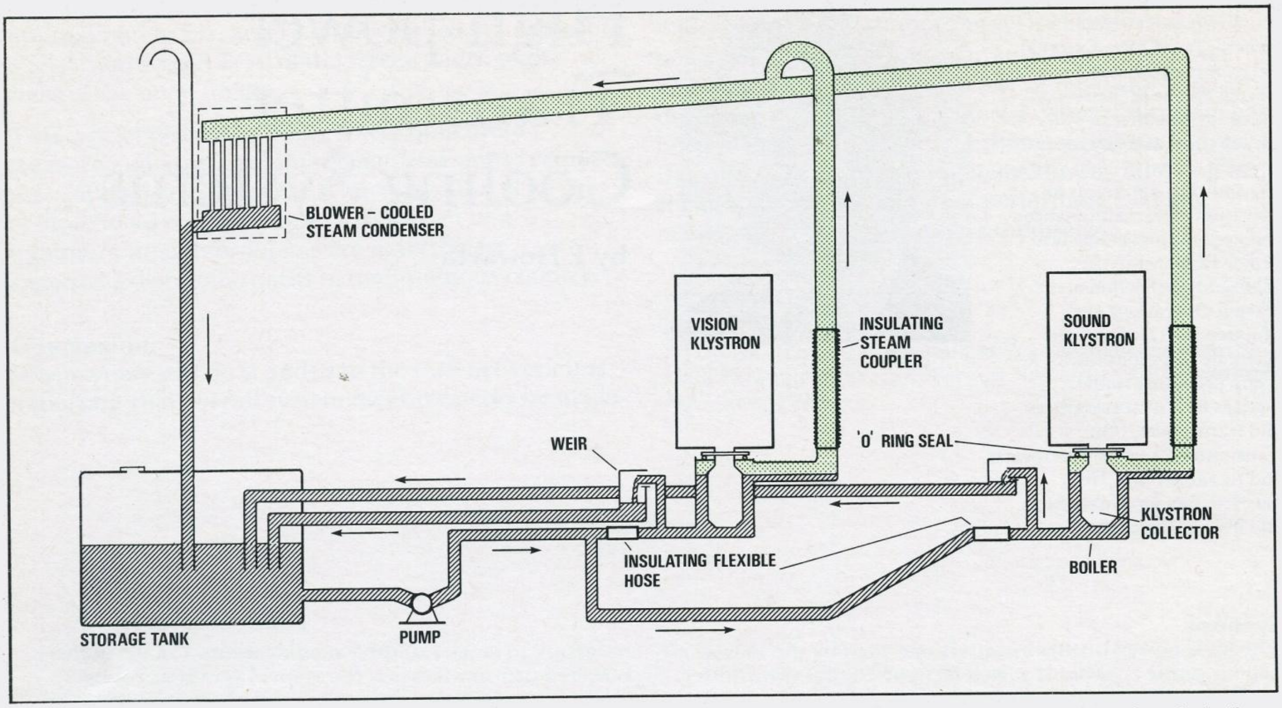


Fig.1. Schematic of the original, pumped cooling system for 6 ¼ / 10 kW transmitters. Water is pumped from the storage tank to the boilers of the vision and sound klystrons where a constant level is maintained in each by the action of a weir. This water is converted into steam by the power dissipated in the klystron collectors and the distillate from the steam condenser is returned to the tank, thus completing the cycle. Unfortunately, when the water is steamed-off any impurities are left behind and become concentrated in the boilers.

The klystron manufacturer, The English Electric Valve Co. Ltd. (EEV), arranged for chemical analysis of samples of water taken from the boilers and water storage tanks in the cooling system of several stations, as well as an analysis of the corrosion products on the collectors. In all cases the results indicated that the chloride ion concentration in the boiler was the cause of the trouble. Further investigation showed that at the stations most severely affected, the demineralised water produced from local piped supplies by an on-site demineraliser had chloride concentrations in excess of 100 parts per million (ppm). Instructions were then issued for future supplies of demineralised water to be purchased from commercial suppliers and for the use of the on-site demineraliser units to be discontinued.

For several months thereafter, klystrons were lifted from their boilers at regular intervals in order that their collectors could be inspected for signs of corrosion, and it appeared that the corrosion problem had been effectively eliminated.

But eventually it was found that corrosion was still occurring albeit to a greatly reduced extent. Another disturbing fact was that this corrosion was now found to be occurring at stations previously unaffected and, in some cases, which had never used on-site demineralising plants. Chemical analysis again confirmed that the cooling water contained a high chloride content.

In the meantime the klystron manufacturer had asked the Metal Users Consultancy Service of the British Non-Ferrous Metals Research Association (BNF) to fully explain the formation of the corrosion which was then believed to be due to thermo-galvanic action. It was obvious that a specification for the water was required and the consultants were asked to determine the maximum acceptable level of impurity in an operational system. The consultants' report confirmed that, if the cooling water contained a sufficiently high chloride ion content, the boiler and klystron collector would provide the necessary conditions for a thermo-galvanic current to flow, see Fig.3.

In the cooling system as originally designed, Fig.1, water was pumped to the boiler, and the weir, external to the boiler, served to maintain the correct level of water in it. Thus, as the water in the boiler was steamed-off by the power dissipated in the collector,

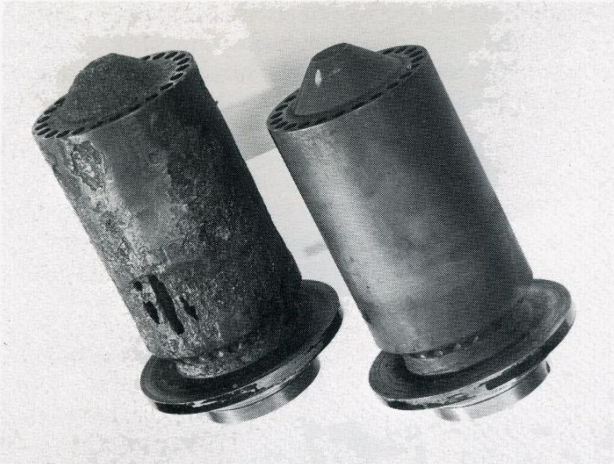


Fig.2. The photograph shows two collectors of klystrons after use in 10 kW transmitters. That on the left-hand side had been used for 20,000 hours in a low-contamination environment; the other had been used for a total of only 5,000 hours. In the latter case severe corrosion resulted because, during part of this time, it had operated in a contaminated water system.

(Photo by kind permission of English Electric Valve Co. Ltd.)

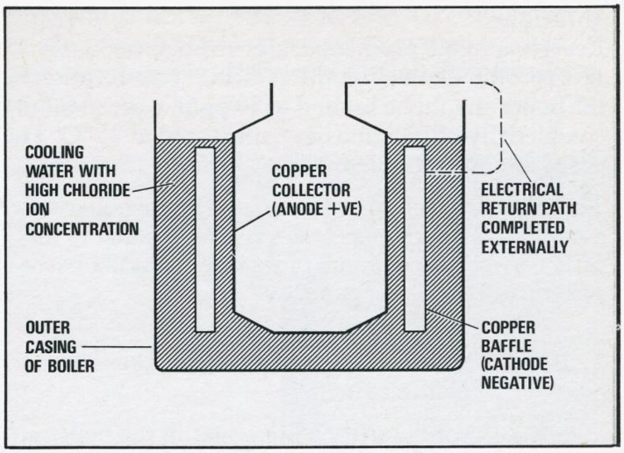


Fig.3. The thermo-galvanic circuit. The surface of the collector acts as a heat source at the temperature of boiling water and therefore a temperature gradient exists between this and the surrounding copper baffle. The external electrical return path (shown dotted) completes the circuit and if the conductivity of the water exceeds 70 μmho cm^{-1} the thermo-galvanic current will be sufficient to cause progressive corrosion which in time will result in the failure of the klystron.

the level was continuously maintained by the pumped supply. Therefore, over a period of time, the complete contents of the storage tank were passed to the boiler, were steamed-off, condensed and returned to the storage tank. Consequently, any impurities in the water would, over a number of hours, accumulate in the boiler, and at the same time the purity of the water in the storage tank was improved.

Another problem experienced with the pumped system was water loss which, at any installation, averaged 1.5 gallons per week.

The storage tanks, when full, contained 35 gallons and a water alarm was raised when the amount fell to 15 gallons. This allowed a loss of 20 gallons, which at the rate of 1.5 gallons per week rendered it necessary to visit each station once every thirteen weeks simply to top-up the water systems (assuming there was no other commitment). This was considered an unacceptable maintenance burden.

There were various reasons for this high water consumption. After only short periods of operation some pumps started to leak. In some cases the leaks were so bad that the complete contents of the storage tanks were lost within only a few days. On investigation it was found that a rubber deposit was adhering to the carbon seals in the pumps, leading eventually to leakages at the pump glands. This deposit was similar to that found on the sides of the storage tanks and was obviously collecting in the pump after circulating through the system. Further leaks developed due to deterioration of the rubber hoses and failure of the union seals. Subsequent investigation showed that, by contact with the heated demineralised water, the rubber hosing deteriorated after approximately six months. Furthermore, klystron boiler 'O' ring seals made of Neoprene rubber, see Fig.4, had gradually been introduced into the system, and it was found that, by reason of the high temperature, these rings hardened within about two months. Once this had occurred, should the klystron, or klystron trolley, be subjected to a mechanical vibration or shock sufficient to rock the klystron on the 'O' ring, the seal would break and thereafter there would be a continual loss of steam until the klystron was removed and the 'O' ring replaced. Such a steam leak could, if it went undetected, result in the failure of the klystron and of the radiation suppressor plate.

Finally, small losses of steam were unavoidable because a vent was installed on the output of the steam condenser to ensure that the system operated at atmospheric pressure. Consequently, under certain conditions, water vapour was vented to the atmosphere.

Solutions

Reverting to the problem of klystron corrosion the BNF recommended that the chloride concentration in the boiler should be limited to 30 ppm, equivalent to a conductivity of 70 μmho cm $^{-1}$ measured at 25°C. This posed a serious problem.

The concentration of contaminants in the boiler, after a number of hours' operation, is proportional to the ratio between the amount of water circulating in the system and the boiler capacity.

If X_T = conductivity of the water in the tank before switch-on

X_B = conductivity of the water in the boiler after a large number of hours of continuous operation

W_T = tank capacity in gallons (approximately equivalent to the amount of water circulating in the system)

W_B = boiler capacity in gallons

then $X_B = X_T \times \dfrac{W_T}{W_B}$

Therefore, if the final conductivity in the boiler is to be 70 μmho cm $^{-1}$, the maximum permissible conductivity of the water in the storage tank before operation is derived as follows:

$$X_T = X_B \times \frac{W_B}{W_T}$$

where $W_B = 1.5$ gallons

$W_T = 35$ gallons

$X_B = 70\ \mu$mho cm $^{-1}$

$$\therefore X_T = 70 \times \frac{1.5}{35}$$

$$= 3.0\ \mu\text{mho cm}^{-1}$$

Demineralised water of purity 1μmho cm $^{-1}$ is readily available commercially, but better than this is not easily obtained. In any case, storage would be a problem because water of extreme purity easily becomes contaminated.

Using water of 1.0 μmho cm $^{-1}$ results in a boiler conductivity of 23μmho cm $^{-1}$ after a number of hours continuous operation. The conductivity increases rapidly over the first two or three days due to oxygenisation and to contaminants in the system.

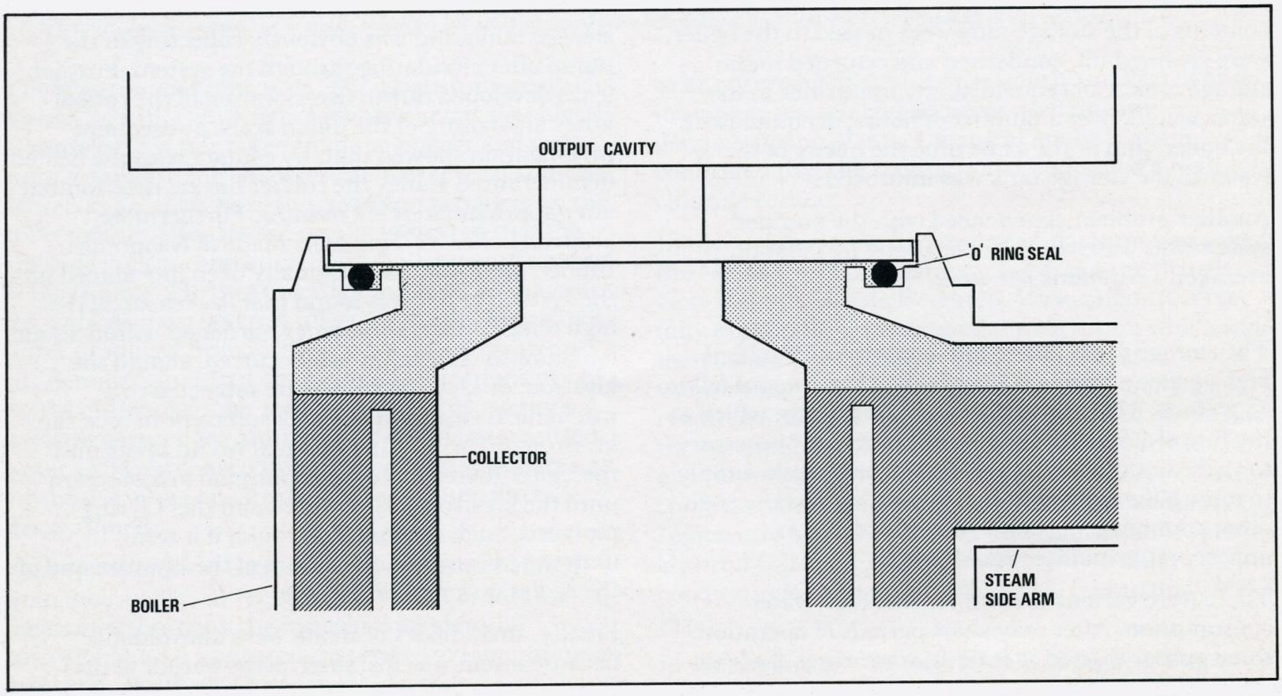


Fig.4. The boiler 'O' ring seal is formed by placing an annular ring, made from a synethetic rubber known by the trade name Viton, under the full weight of the klystron and its cavities. 'O' rings made of Neoprene had been used but these became brittle after only a relatively short time in service, see Fig.5, due to contact with demineralised water at high temperature. Once this occurred the seal would break and there would be a continual loss of steam until a new 'O' ring was fitted.

Therefore, after only a few days of operation it was possible for the maximum permissible conductivity level in the boiler to be reached. This was obviously quite unacceptable from a maintenance stand-point.

It can be shown that the speed at which the chloride level in the boiler builds-up is directly related to the ratio between storage tank capacity and boiler capacity. Therefore, a reduction of this ratio must be implicit in any solution to the problem.

To make any meaningful improvement the total amount of water circulating should not exceed five gallons. This requirement ruled out the pumped system altogether as in such a system it is necessary to have sufficient water to maintain an overflow from the weir even when maximum power is being dissipated at the klystron collector. Also, the pump needs an adequate supply in order to remain primed. Taking these conditions into account any pumped system would require at least ten gallons irrespective of any allowance for wastage. The only acceptable solution, therefore, was to change the system to one of pumpless operation, and so a modification was implemented by the Authority in conjunction with the equipment manufacturer. The proposals for this modification were formulated as a direct result of the research which had been carried out by EEV with the assistance of BNF.

Naturally, this proposal entirely solved the problems of the leaking pumps by rendering the pumps redundant, but the problem with the hoses still remained. As will be seen later, at one stage of the investigation of the water cooling system for the 25kW transmitters, the Atomic Energy Research Establishment (AERE) proposed that all rubber hosing used in the water systems be replaced with Polytetrafluoroethylene (PTFE) lined hoses. Another feature of the proposed pumpless system was to fit pressure relief valves to the steam vent. The purpose of these is to establish a closed system, but, should the steam pressure build up to a value in excess of +12 inches water gauge, a valve will open and the system will vent to the atmosphere. A second valve will release at −12 inches water gauge thus admitting air into the system, and ensuring that no vacuum is created during cooling.

The Neoprene 'O' rings introduced into the system by the Authority, and which had proved unsuitable, were replaced with the type recommended by the klystron manufacturers. The correct 'O' rings are made from a synthetic rubber called Viton (trade name of EI du Pont de Nemours Inc.). Chemically this is a vinylidene fluoride-hexafluoropropylene copolymer which, unlike Neoprene, retains its elasticity when used with demineralised water at high temperatures, see Fig.5.

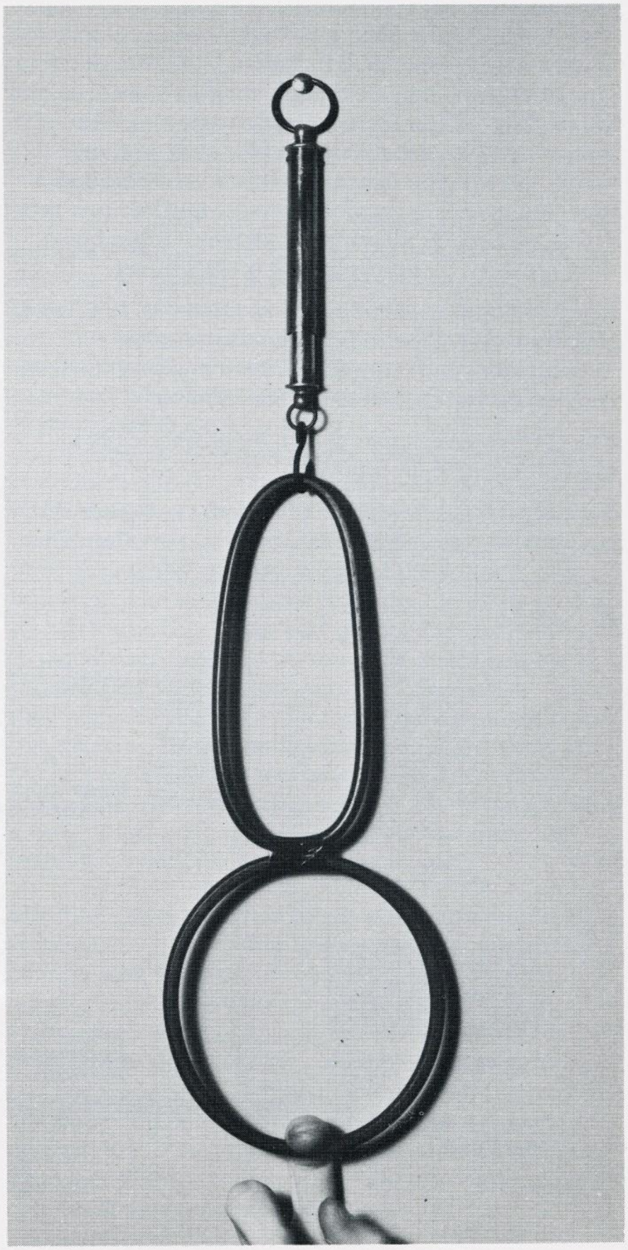


Fig.5. Boiler 'O' rings must remain supple under normal working conditions if the seal is to be effective and steam losses prevented. In the photograph two 'O' rings are subject to the same stress. The lower one, made of Neoprene, has become hard and brittle after only three months in operation, whereas the other, made of Viton, is still flexible after having been in service for 10 months.

The Modification

The new proposals made maximum use of the existing system. Apart from the removal of the weir and the addition of another level switch the boilers remained unchanged, but the existing water storage tanks were removed from the pit and installed above boiler level. The pumps having been removed, a solenoid-operated water valve was installed in the feed line. The return pipe from the steam condenser, instead of feeding into the storage tank, was connected to a point in the system between the solenoid water valve and the boiler. Finally, the steam condenser vent pipe was modified to accept the new pressure and vacuum relief valves, as already mentioned, and the rubber hoses were replaced by others having a PTFE lining.

The first station so modified was Dover, in 1972, and after a successful period of validation similar modifications were applied to the remaining thirteen stations during the following five months.

The complete system is shown diagramatically in Fig.6. It operates as follows:

The supply of water from the tank to the boilers is governed by the solenoid-operated water valve. This in turn is controlled by the transmitter logic associated with a water level switch fitted to the boiler. At a predetermined low level the switch operates, thereby opening the water valve and topping-up the boilers. While the water in the boilers is steamed-off by the heat dissipated in the klystron collector the level is maintained initially by water from the storage tank. As the system continues to operate, the condensate from the steam condenser is returned to the water line feeding the boilers and a balance is eventually reached without the need for further topping-up. In a perfect system this would then continue indefinitely, and so the amount of water circulating would be the amount required by the two klystron boilers (one for vision and one for sound), the water in the supply pipe and the water required due to the inertia of the steam condensation cycle. In all, this would be about five gallons. In practice, some losses do result from leaks and from occasional operation of the pressure relief valve. Topping-up from the storage tank is then automatic.

System Performance and Maintenance

As a result of these modifications, the average weekly water consumption per transmitter is approximately

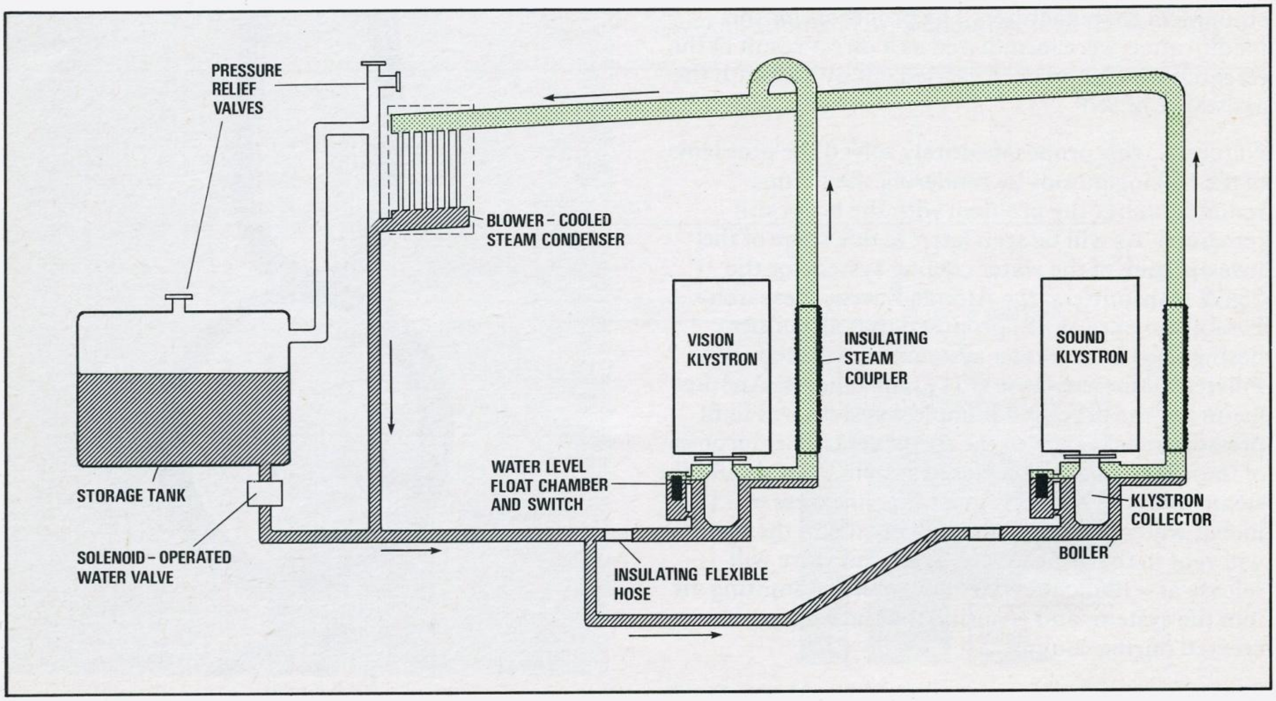


Fig.6. Schematic of the pumpless cooling system, as modified, for 6 ¼ / 10 kW transmitters. The water level in the klystron boilers is monitored by the float chambers fitted to the sides of the boilers as shown. When this falls below a predetermined level a float switch operates causing the solenoid-controlled water valve to actuate thus topping-up the system from the storage tank. In practice, the control is exercised entirely from the float switch associated with the vision klystron since, of the two, this makes the greater demand for water. But it is to be noticed that the condensate is returned direct to the pipe feeding the boilers, and so once the system has reached a balance little topping-up is required.

0·6 gallon per week as against 1·5 gallons with the original pumped system.

The conductivity of the water in the boilers is monitored at three-monthly intervals, as can be seen from the following extracts from the Preventive Maintenance Schedules.

UNDER-TAKEN AT INTER-VALS OF	ITEM NO.	SDR SUB-UNIT CODE	JOB DESCRIPTION	REF. NO.	MAN HOURS
EiC's discretion	0/31	ASOO	Top-up klystron cooling storage tanks	SM1 M.3.2	0·3
3 months	3/01	ASOO	Measure conductivity of cooling water	SM1 M.3.2	0·8
	3/02	ASOO	Inspect water and steam systems for leaks		0·4
12 months	12/10	ASOO	Inspect lagging and connectors on steam pipe-work		0·6
	12/11	ASOO	Replace rubber sealing rings on klystron boilers	SM1 M.3.1	4·0
	12/13	ASOO	Replace coolant in klystron cooling storage tanks		1·5

When the conductivity of the water in the boiler reaches 50 μmho cm^{-1}, which typically might occur after a useful life of about four or five months, the boiler is drained and then refilled from the storage tank. To minimise the amount of work necessary under Corrective Maintenance, the needs of the water cooling systems are scheduled under Preventive Maintenance.

The items on the foregoing schedule are self-explanatory, but item 12/13 deserves special mention. Because the water in the storage tank is stagnant, organic growths, as well as copper carbonate, can form over a period of time. The water in the storage tanks is changed when the conductivity has increased to 10 μmho cm^{-1}. Additionally every twelve months the tank is emptied, cleaned and refilled with new commercial grade demineralised water of conductivity 1·0 μmho cm^{-1}.

The manhours normally required per transmitter (vision and sound), based on experience, are shown in parenthesis alongside the individual items, but it should be remembered that there are two sets of vision and sound transmitters on each site.

COOLING SYSTEM FOR 25 kW TRANSMITTERS

The 25 kW transmitter cooling system is similar to the original system for the 6 ¼ / 10 kW transmitters, see Fig.7. But, arising from the use of 'five integral cavity' klystrons, which are a feature of the 25 kW transmitters, and the fact that this type of klystron is mounted with its collector uppermost, the problems associated with this system were, in many respects, significantly different. Basically, the larger klystron requires more cooling than the 6 ¼ / 10 kW version. A continuous flow of water at a minimum rate of 1·6 gallons per minute is required for cooling the body of the klystron, while the focus coils are also water-cooled and require a minimum flow of 1·2 gallons per minute. Both these requirements demand the use of water pumps.

As in the original 6 ¼ / 10 kW system, the water is pumped from the storage tank to the klystron but in this case is required to flow upwards through the boiler and into the weir above the klystron, the overflow being returned to the storage tank. In this way, unlike the system described earlier, there is a continuous flow of water through the boiler, thus precluding the local build-up of any high concentration of contaminants. Consequently, the contamination is uniform and at a comparatively low level throughout the system. The conductivity is measured every three months, and when it reaches a level of 33 μmho cm^{-1} the whole of the water is replaced. The steam outlet from the top of the weir is routed to the condenser and the condensate returned to the storage tank. By reason of the extra cooling required for the klystron body and focus coils, together with the large amount of power dissipated in the collector, supplementary cooling of the water in the reservoir tank is necessary. Using a separate pump, the water from the tank is made to pass around a water cooling matrix below the steam condenser and is then returned to the reservoir tank.

It is interesting to note that the heat balance of the system is such that if, for any reason, the water flow be increased beyond the recommended rate, the temperature of the water *rises*. This is because the system then tends to become water cooled, rather than vapour phase cooled, and in consequence the cooling efficiency is reduced. The temperature of the system would continue to rise until the transmitter tripped due to the operation of pre-set thermostats in the water feed to the klystrons. These are set to operate at a water temperature of 65°C.

Operational Problems

Water leaks were occurring as in the 6 ¼ / 10 kW system, and for similar reasons.

The carbon seals on the water pumps became pitted with rubber debris that was circulating in the system.

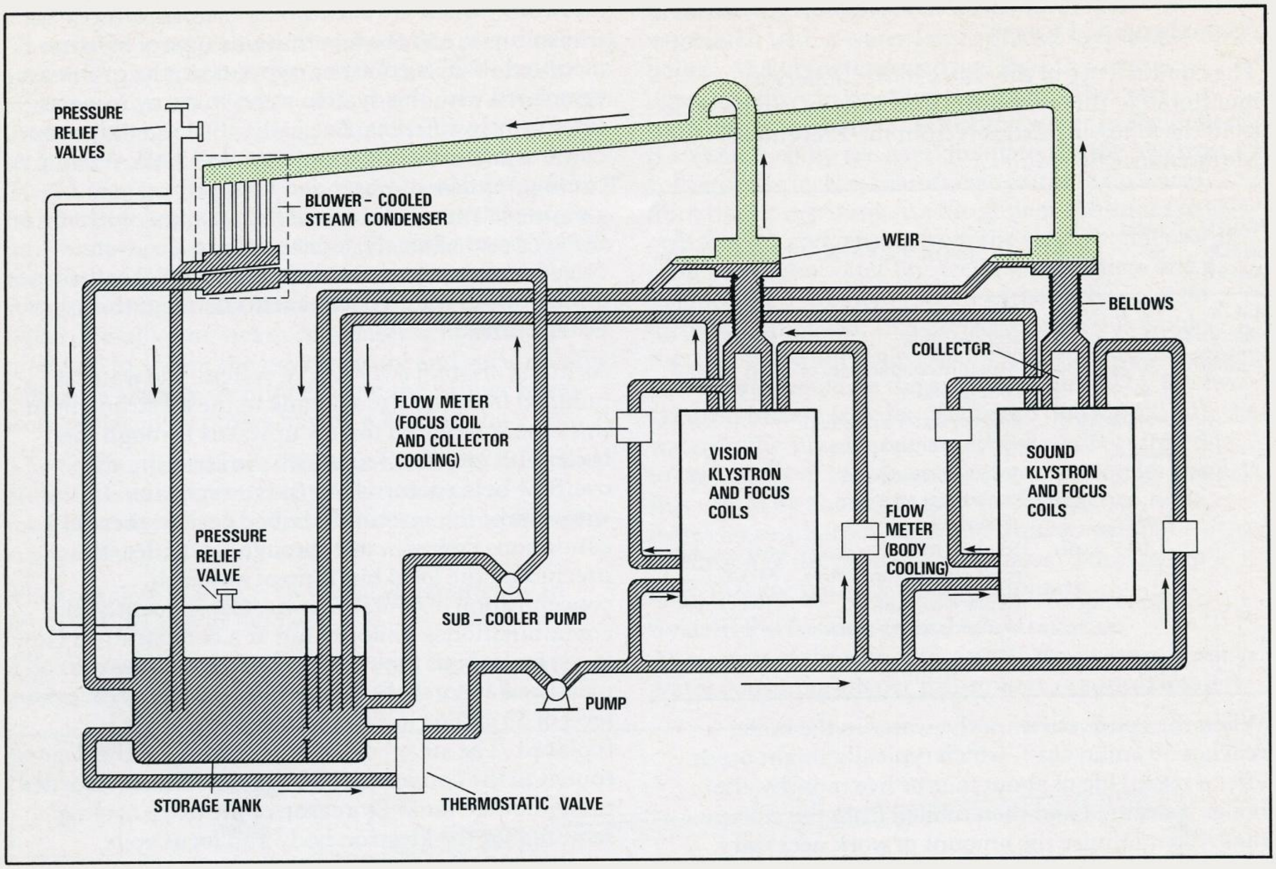


Fig.7. Schematic of the cooling system for the 25 kW transmitters. This type of klystron, unlike the smaller version, is mounted with its boiler uppermost; also, a continuous flow of cooling water is required to pass round the body and surrounding focus coils in addition to providing vapour phase cooling for the collector. A pumped system is practical in this case because contaminants can freely circulate around the system and hence do not form a region of high concentration around the collectors. Due to the high level of heat that has to be dissipated, a separate circulatory system comprising a sub-cooler pump and a water cooling matrix in the condenser is provided to cool the water in the storage tank.

This would eventually cause a leakage. The action of hot demineralised water on the rubber hoses led inevitably to the formation of small rubber particles which were then free to circulate through the system. Connections to the klystron body and focus coils are made via self-sealing, quick-release water couplers. The rubber washers used for sealing these couplers were of a quality which caused leakage after only short periods of use. Similarly, the connections between the boiler and weir, see Fig.8(a), and those between the weir and the steam pipe, were made by rubber bellows which deteriorated rapidly from the effects of demineralised water at boiling point. Cracks appeared in the rubber which deepened with time and eventually leaks occurred. Leaks in the rubber bellows constituted a serious problem for two reasons:–

(a) there was a high risk that the bellows would burst during maintenance operations, and the consequent danger of serious injury to staff from boiling water and steam;
(b) should any water come in contact with the klystron gun and modulating anode assembly, a high voltage flash-over would occur which could damage the klystron.

For these reasons, new rubber bellows were fitted at regular six-monthly intervals – a costly procedure in time and material.

The Solutions

The Authority used the consultancy service provided by the Atomic Energy Research Establishment (AERE) for advice on the problems in the 25 kW transmitter cooling system. After investigation, the AERE recommended that, wherever possible, all rubber in contact with the water in the system be removed and replaced with PTFE. Being a

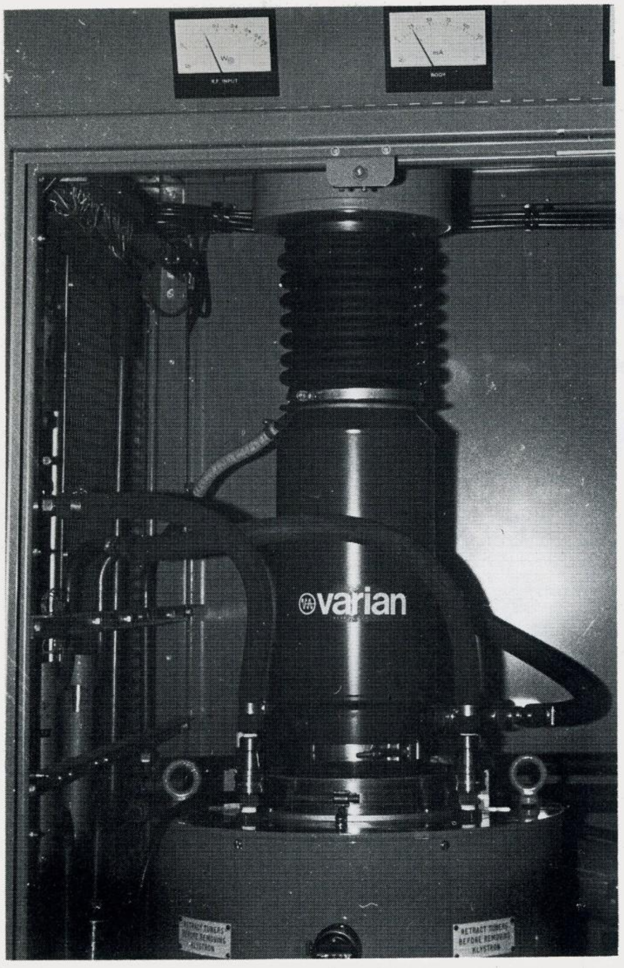


Fig.8(a). The rubber bellows or 'boots', shown here, that were originally fitted between boilers and weirs of klystrons used in the 25 kW transmitters cracked after having been in service for a relatively short period of time with the consequent dangers of leaking or even bursting. Also, rubber particles which crumbled away from the inside surfaces of these bellows and then circulated around the system were the cause of pump failure.

thermoplastic, PTFE softens when heated and hardens on cooling. It has a usable temperature range of −270°C to 200°C, is resistant to a wide range of chemicals and has high insulating resistance. It therefore appeared to be an ideal material and its use in place of rubber seemed likely to greatly improve the reliability of the water pumps. Suitable PTFE hoses having couplers swaged on the ends were obtained. It is a point of interest that similar hoses had been previously rejected as they had a maximum pressure of only 45 lb/in², whereas the requirement was for a hose to withstand a minimum pressure of 90 lb/in². However, the hose finally selected was a modified version of the 45lb/in² hose which, incidentally, had been produced for the aircraft industry and incorporated a nylon braided outer sheath enabling it to withstand working pressures up to 150 lb/in².

With regard to the washers for the quick-release water couplers, the manufacturers, after an investigation, supplied a rubber washer capable of withstanding the rigours of the operating environment. Although this is out of keeping with the recommendation to remove rubber from the system, it appears there is no satisfactory alternative material for this particular item. Moreover, the replacement of the rubber bellows with a PTFE alternative proved a major design problem. PTFE, having a very low coefficient of friction, 'creeps' when under mechanical stress, a characteristic which is a distinct disadvantage for this

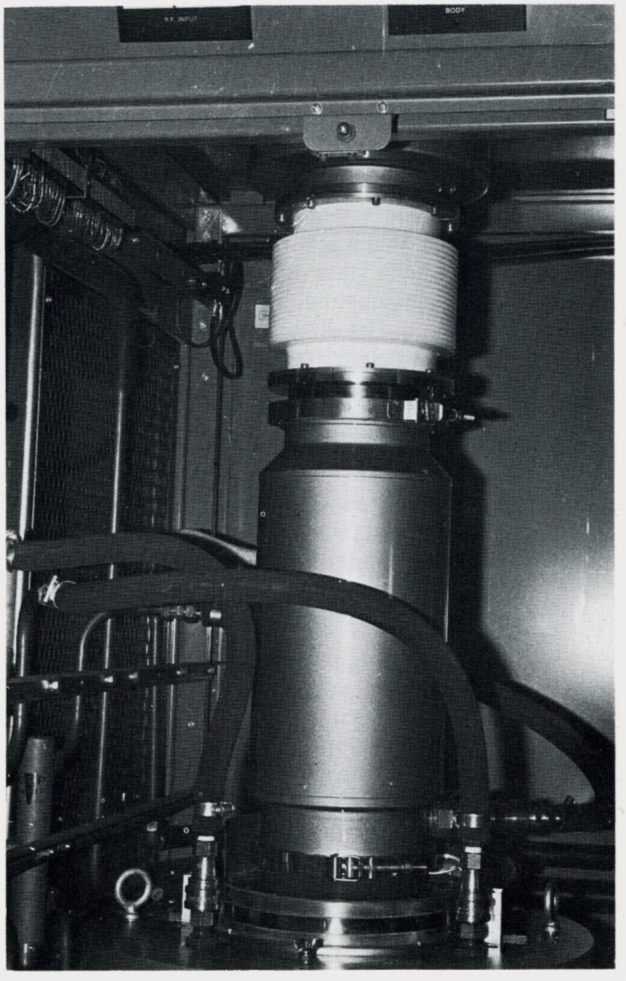


Fig.8(b). The prototype PTFE bellows fitted to a klystron at the Caradon Hill transmitter in place of the rubber type shown in the previous figure, and which proved entirely satisfactory.

particular application. The shape and size of the original rubber bellows had been specifically designed to mate with the boiler and the weir, and there was sufficient flexibility to cater for any alignment variation between the weir and the klystron. It was realised that, in changing to PTFE, some modification would be necessary in order to overcome this problem of 'creeping'.

A prototype PTFE bellows was produced and tested by AERE and, in June 1972, a sample was installed between the boiler and weir of one of the klystrons in the transmitter at Caradon Hill, see Fig.8(b). It proved entirely satisfactory. In the event, the top set of bellows, between the weir and the steam outlet pipe, was dispensed with and was replaced by semi-rigid convoluted PTFE hose; bellows were therefore retained only between the boiler and the weir.

The pattern for the modification was thus established and the IBA's twelve 25 kW stations were modified accordingly, starting with Sutton Coldfield in July 1973.

During the course of this modification programme an incident occurred at the Durris station, near Aberdeen, which resulted in a further pressure relief valve being fitted to the water storage tanks at all 6 ¼/10 kW and 25 kW transmitters. The reason for this was that freezing occurred in the pressure relief valves fitted on the outlet of the steam condenser at Durris, causing the system to become pressurised. In consequence, the PTFE bellows distorted to such an extent that some of the convolutions became stretched to their limit. The original pressure relief valves were located in an unheated area, and so this problem could have occurred at any station during the winter months. A pressure balancing pipe between the output of the steam condenser and the water storage tank serves to prevent any pressure differential which might otherwise be developed. When the transmitter is inoperative a thermostatically controlled immersion heater within the water storage tank prevents freezing and, hopefully, will also provide sufficient heat to protect the new pressure relief valve fitted in the filler cap.

In summary, the need to replace the klystron/weir bellows at six-monthly intervals has been eliminated. The life of the PTFE bellows has not yet been determined, but it is in terms of years rather than months. Pump failures have been reduced due to the removal of the rubber particles from the circulatory system.

Preventive maintenance for the 25 kW system is now as shown on the following extracts from the Preventive Maintenance Schedules.

UNDER-TAKEN AT INTER-VALS OF	ITEM NO.	SDR SUB-UNIT CODE	JOB DESCRIPTION	REF. NO.	MAN HOURS
EiC's discretion	0/31	ATOO	Top-up klystron cooling storage tanks	SM1 M.3.2	0·3
3 months	3/01	ATOO	Measure conductivity of cooling water	SM1 M.3.2	0·8
	3/02	ATOO	Inspect water and steam systems for leaks		0·5
12 months	12/10	ATOO	Inspect lagging and connectors on steam pipe-work		0·5

Conclusions

In the operation of cooling systems for high heat-flux devices it has been the Authority's experience that careful attention must be given to preventive maintenance and operating conditions. The modifications made to the cooling systems of both the 6 ¼/10 kW and 25 kW transmitters have reduced the maintenance load and enabled the IBA to provide a more reliable service.

JIM CLARKE joined the Authority in 1955 from the BBC where he had worked on both short and medium wave radio transmitters, and at the Wenvoe television station. He was one of the original staff at the IBA's Lichfield transmitting station, employed as a Senior Shift Engineer, and was later appointed Assistant Engineer-in-Charge (AEiC). He transferred to become AEiC at the St Hilary station in S. Wales when it opened in 1958 and ten years later became Engineer-in-Charge at Belmont until it was unmanned in 1972. Since then he has occupied the post of Safety Officer with special responsibilities as described in this article.

Safety

by J R Clarke

Synopsis
The Authority has always regarded the safety of its operating staff as a matter of great importance and in 1972 it appointed an experienced transmitter engineer as Safety Officer, whose full-time responsibility is to consider all aspects of accident prevention and to advise accordingly. Unfortunately, there is no simple formula for safety. Formal regulations and procedures form a necessary part of any safety policy, but are of little value unless the staff who are at risk can be persuaded to take them seriously. Since the more hazardous operations tend to be undertaken by small groups of two or three persons working at remote sites without supervision, it is essential to engender a strong sense of personal responsibility in all concerned.

The greatest number of accidents, although not usually very serious, arise not from highly technical operations but from very ordinary activities such as the lifting of goods and walking on slippery or uneven surfaces. It is a salutary lesson that statistically the most likely cause of serious personal injury is the motor car!

Introduction

The safety of operational personnel has always been given high priority in the IBA, but with the increase in equipment complexity and the growth of new legislation it became necessary to appoint a Safety Officer who could give undivided attention to all aspects of safety. Such an appointment does not in any way diminish the responsibility of all staff to themselves or to those in their charge; rather, it provides a central reference point where all aspects of safety throughout the IBA can be considered and from where advice, guidance and instruction can be obtained.

The great majority of technical broadcasting equipment will usually incorporate basic safety measures such as interlocks, earthing switches, covers over live terminals, fail-safe logic, etc. as essential features of its design. Notwithstanding this, however, engineers concerned with operation and maintenance may, on occasions, be exposed to hazards of one sort or another, be they electrical or mechanical, and it is to minimise these dangers, and the possible injury that might result from them, that this article is concerned.

Experience over the past few years has shown that it is necessary to consider every accident or potential hazard from the safety aspect – i.e. how to prevent an accident rather than lay the blame; and to discover the basic cause rather than the final link in the chain of events leading to it. Such an exercise can be time-consuming and requires a mental approach which is in general acquired by training and developed by experience. This approach is best achieved by adding safety training to existing knowledge and experience of the relevant engineering discipline, rather than the other way round.

Accident Records, Prevention Programmes and Safety Inspections

The accident rate within the IBA is low in comparison with most other industries and is consistent from year

to year for minor accidents (see Appendix). The incidence of serious accidents is too small to establish a pattern over so few years. Nevertheless, because of the very serious results of, for instance, a fall from a mast, it is important to try to foresee potential hazards. It is not often possible to be sure if actions which have been taken have effectively prevented an accident from occurring, but when an accident or near-accident does occur, the failure of the system becomes all too obvious.

An accident prevention programme is a long-term activity, comprising initial instruction and follow-up refresher courses. Probably the most significant aspect of any safety instruction is that staff are made more conscious of the hazards, often by discussing the long-term effects of injury or damage which might result. A particular instance of this is when staff are given training in 'First Aid'. It is well established that accident rates can fall substantially following such training although, without refresher courses, the rates rise again in due course.

Working conditions in the IBA are such that personnel, other than office staff, usually work in small groups and have to rely on their own attention to safety to avoid accidents either to themselves or to their colleagues. The most effective way of achieving this is to ensure a sound safety training in the work to be done, and to teach the safe way of doing things during initial training so that bad habits are avoided from the start. It should be appreciated that many of the day-to-day activities within the IBA are fraught with danger unless the staff are properly instructed. It is to ensure that this type of instruction is provided that many of the statutory regulations have been made, particularly those contained in the Factories Act, which is now in the course of being replaced by the Health and Safety at Work etc. Act.

In some cases work patterns have changed, and methods which at first might have been acceptable, if not entirely satisfactory, continue to be used even though new hazards may have been introduced later. Such instances can often be recognised by someone disciplined in looking for this type of situation, but otherwise are likely to remain unnoticed.

It is essential that formal regulations be drawn-up and made available to all concerned. The IBA publishes its own Safety Regulations which are designed to cover every aspect of safety within the Authority, and copies are issued to all engineering staff. With the changing pattern of work it is further necessary to review this publication at intervals of two or three years. However, it is not possible to cover every conceivable hazard, and it is emphasised that ultimately the individual members of staff are responsible for their own safety and that of their colleagues. As with any other form of instruction, the Regulations, even if made mandatory, can only draw attention to the hazards. In the final analysis it is a well-ordered pattern of human behaviour that counts.

Contacts With Other Professional Organisations

There are few, if any, problems which are unique to the IBA. In almost every case similar problems have already been met and overcome elsewhere. Close links exist between the safety officers of different organisations and there is always an immediate willingness to discuss each other's problems and offer advice. In some cases, problems are directly shared, as between the IBA, the programme contractors, the BBC, Post Office, Electricity Boards, mast constructors, etc., and with so much similar equipment the IBA and BBC in particular follow, as closely as possible, similar safety precautions. To this end very close liaison is maintained.

Nevertheless, the combination of circumstances within the IBA, such as the operational and maintenance techniques in use and the structures and equipment which are employed, do present a pattern which is different from any other, and therefore safety precautions have always to be considered with regard to each specific case or usage, rather than merely to follow standard industrial practices. It has therefore become necessary to establish a continuing liaison with many national establishments. These include the Fire Service, the Employment Medical Service, the National Engineering Laboratory and the Construction Industries Training Board, as well as with the Royal Society for the Prevention of Accidents, the British Safety Council and the manufacturers of safety equipment. In this way it is possible to ensure that current practical methods and safety measures are as effective as can be reasonably achieved.

The basis of any safety regulations is that all appropriate legal requirements should be fully met. Until recently these have largely been specified in the Factories Act, the various regulations made under that Act, and the Offices Shops and Railway Premises Act, As mentioned above, these are now being consolidated in the Health and Safety at Work etc. Act which covers almost every aspect of industrial safety. Unfortunately the interpretation of many of these regulations is not clear and in these cases, the help of the Factories Inspectorate is especially valuable.

In the more general field, it is useful to be able to discuss practical experience with other organisations and in doing this an important point of contact is the Occupational Accident Prevention Group.

Advisory Responsibilities

The Safety Officer is responsible for advising on all aspects of safety and for supervising the executive action necessary to achieve it, but has no direct responsibility either for the safe behaviour of staff or the operation of equipment. This lies with the managers and the staff themselves.

In practice, absolute safety is an impossibility. It cannot be achieved in normal life, and to attempt it at work would necessitate the inhibiting of every physical action. A balance has to be achieved between probability and degree of risk.

No safety budget is unlimited and so, as with most other things, the available funds have to be allocated to best possible advantage. One must consider whether an increase in expenditure on any given project will have an appreciable effect in reducing the risk involved. There will be a point at which the 'cost-effect curve' will flatten out and a decision has then to be made as to whether the residual risk should be accepted, or the project changed or even abandoned. These decisions are taken by the line managers, but it falls to the Safety Officer to furnish them with all relevant details and to make recommendations as appropriate.

Safety Devices – Their Design, Selection and Use

The quality of personal safety equipment ranges widely from the simple and inexpensive to the highly sophisticated and usually very expensive. This latter is also often unpopular with staff by reason of its complexity. The most effective equipment is that which is most widely used, and it is always helpful to obtain various suitable samples (e.g. eye protectors) and obtain comments from staff on the merits of each. This provides a dual benefit – it ensures a degree of acceptance of the equipment, and gives the staff a sense of involvement in the question of safety at the decision stage. This is important. In most industries some control over the use of safety equipment can be achieved by supervisory staff, but in the case of the IBA most of the hazardous work is done by small teams of two or three, working in isolation. In such cases, the use or rejection of, say, eye protectors, rests entirely with the individuals exposed to the hazard. The need for their acceptance of the equipment provided, as well as fully appreciating the risks involved, is obvious.

As to design recommendations, much control is already exerted by statutory regulations imposed on manufacturers. But it is frequently worth investigating whether items such as electrical fittings are properly suited to the conditions which will exist in practice, because the actual operations to be carried out and the conditions prevailing in any given area may not be clearly appreciated by the designers.

It is neither practical nor desirable to design protective enclosures in such a way that access to live parts is not possible. The usual principle adopted is to arrange that doors or covers used to protect personnel from coming into contact with dangerous voltages can only be opened by using some sort of tool such as a key, screwdriver, spanner, etc; only covers which do not conceal live components may be removed using the fingers alone.

For enclosures where a more ready access is required, the use of mechanical interlocks ensures that all exposed parts are safe before access can be gained. This implies that the electrical power must first be switched off and charged capacitors and conductors earthed before the doors may be opened; safety is then automatically ensured.

The provision of interlocks of this type is generally only practical at the design stage when they can be incorporated without serious difficulty. The integrity of an interlock system fitted to an equipment enclosure must leave no room for doubt because, when operated, it is accepted by staff as a complete assurance that all is safe within. The design of interlocks, like that of the rest of the equipment, is a matter of continued feedback between user and manufacturer and must be given the closest attention to ensure that the safety measures are complete and that the design is such that its operation will be reliable throughout the life of the equipment. Moreover, since equipment maintenance is often carried out under emergency conditions, and almost always under pressure of time, it is important that, as with all safety devices, it must be simple to use so that risk of operational error is reduced to a minimum, particularly since electrical accidents are likely to be serious – and sometimes fatal.

It must be emphasised that, as in the matter of finance, there are never enough resources available to carry out all safety procedures at once, nor can any one person be conversant with all aspects of an organisation with as wide a field of activities as the IBA. The best that can be achieved is a reasonable practical knowledge of those operations which are the most likely sources of serious accidents and to

maintain close contact with the staff most at risk, while having an official position of parity with the line managers responsible for safety at stations and within specialist sections.

It is generally accepted that a Safety Officer can be effective only by achieving the aims of safe behaviour by persuasion. When penalties, or the threat of them, become necessary, the system has failed.

Practical Aspects
The most likely cause of accidents in the IBA is the driving of motor vehicles since, in all, the staff drive a total distance of about one million miles a year over all sorts of roads, from motorways to site access roads negotiable only by field cars, and under all climatic conditions. Despite this, the IBA accident rate is below the national average. This is as might be expected, since IBA drivers have, in general, ample experience and use well maintained vehicles.

No formal driving instruction is provided, but staff are encouraged, where practicable, to attend skid-pan training courses and to report any aspects of vehicle risk which come to their attention. This information is then circulated to all departments.

With so many small groups of staff working at remote sites, on tall masts or complex electrical equipment, often having to walk or drive across rough country, there is always a risk of accident or illness ranging from asphyxiation, heart failure or severe bleeding to minor cuts and bruises. For staff thus deployed, the one-day first-aid courses given by the British Red Cross Society and St. John Ambulance have proved useful. The syllabus is chosen to suit the circumstances and is backed up by refresher courses and a 'travelling' resuscitation training dummy. The accent is placed on resuscitation, heart compression and the control of bleeding. The courses are designed to provide an adequate knowledge for dealing with emergencies by keeping any casualty alive and as comfortable as possible until medical aid can be obtained.

Masts and aerials present potential sources of hazard which can prove fatal without care and attention to personal behaviour, and if the equipment, including safety equipment such as fall arresters, is not maintained and used correctly. With increasing programme commitments the essential maintenance of feeders and aerials has lately been severely restricted, and so the problems of working under artificial light and in the vicinity of live aerials have been closely studied to assess the additional hazards involved and the means of overcoming them.

The use of high-power transmitters introduces the problem of electromagnetic radiation fields. Aerial systems are designed to ensure a minimum practicable level of radiation in areas where persons may climb but some radiation will inevitably exist. Electromagnetic radiation levels can be monitored by portable measuring equipment. The maximum permitted limits of power intensity and duration of dosage are to be as agreed internationally, but as yet unpublished, by the Commission of the European Communities. The present limit is $10mW/cm^2$ for continuous radiation, or the equivalent as averaged over six minutes with an absolute maximum of $100mW/cm^2$.

With mast heights of up to 1,265 ft the problems of maintaining both the masts and the aerials they support can present special problems requiring the use of lifting appliances which, themselves, require very close attention to avoid trouble. Normally, lifting appliances cannot be permanently fitted to masts for structural as well as financial reasons (except in the special cases which apply to two cylindrical masts and one concrete tower). They must therefore be transported from site to site as occasion demands. The rigging and operation of mobile winches and associated lifting ropes, guide ropes and skips are skilled tasks requiring specialist training and the closest attention to detail on account of the very serious injuries which an accident could cause. This has been highlighted by the one serious accident which has occurred. In this, a number of conditions existed, none in itself dangerous, but which together resulted in a severe leg injury to one staff member. This is typical of accidents that can and do happen if the circumstances leading up to them are not recognised and corrected in time. Discussions with safety officers of other large organisations have in almost every case brought to light parallel situations where a number of relatively minor changes in working conditions have collectively produced a situation resulting in personal injury. Because serious accidents are rare occurrences it is not easy to identify the presence of such risks until after an accident has occurred. Knowledge that similar conditions have existed elsewhere can be a very important factor when considering what action should be taken to prevent the development of trains of circumstances which could finally result in serious accident. It must be emphasised that few accidents can be traced to the failure of any one person or piece of equipment. In almost every case the accident has resulted from the unexpected occurrence of a number of changes in work patterns, or personal activities, neither of which, considered singly, would have been significant.

Fig.1. Testing the system. A climber wears a safety harness attached to a fall arrester. This device runs on a rail secured to the mast. It runs freely during normal climbing, up or down, but locks on to the rail in the event of a fall.

Pause to check that . . .

The device has locked onto the rail.

Taking the weight.

Relax, and . . .

Suspended safely.

The more likely causes of serious accidents, such as motoring, climbing or working on electrical equipment, must receive first attention, but other risks also exist and have to be guarded against. Fire hazards are not likely to be extensive because of the safety factors included in the construction of buildings, but there is always the risk to individuals if safety precautions are not followed. Kitchens and workshops where flammable materials are handled are obvious cases. A less obvious one is that of using petrol-driven generators in places where fires could start and spread. Workshop practice is well documented and presents few difficulties which cannot be resolved by reference to the appropriate regulations.

A problem exists with regard to safety belts and harnesses used when climbing masts. A wide range of different types exists, but those more effective in preventing injury in the event of a fall are often the more complex and restrictive of movement. A belt, though likely to cause injury to a person falling, will arrest the fall and prevent a fatality. The principle employed is that of giving climbing staff a choice of equipment and to encourage them to use a harness, rather than a simple belt.

Quite ordinary, every-day activities such as the lifting and handling of equipment and materials, using ladders, handling toxic and corrosive substances, working in noisy and dusty conditions etc., are not without their hazards. These are the major causes of injury in the IBA and although such injuries are usually slight, in total they create a considerable amount of suffering and absence from work. These lesser but common hazards are often the more difficult to deal with because they concern personal behavioural patterns formed over many years and changes are not often welcomed or even possible. Nevertheless, it remains one of the Safety Officer's tasks to advise and guide, and to instil a sense of responsibility for safe bahaviour in *all* staff, not only those who perform the more hazardous duties.

At all times, and in all things, the cardinal rule is *better be safe than sorry*.

APPENDIX

Accidents to IBA staff on duty are monitored by the issuing of Accident Report Forms. These are required for any injury, however trivial, but in practice it is certain that many such injuries go unreported.

The purpose of the Return is:

a) to assess the numbers and types of accident year by year to indicate accident trends,

b) to have a reference in case of later development of severe illness which might be attributed to the accident.

The Table below relates to reported accidents concerning the Station Operations and Maintenance Department only, numbering about 250 staff.

Cause of Injuries	*1970/71*	*1971/72*	*1972/73*	*1973/74*	*1974/75*
Handling Equipment	3	–	2	5	2
Falls of Persons	4	5	3	3	2
Machinery	–	1	–	–	1
Impacts	4	1	4	4	3
Hand Tools	2	2	–	–	–
Electrical	1	1	1	–	4
	14	10	10	12	12

Analysis of 1974/75 Injuries

Handling equipment

a) Back injury whilst hitching a winch to a Land Rover

b) Cut hand whilst lifting a duct cover

Falls

a) Sprained ankle – slip on steps

b) Shoulder damage – fall on floor

Machinery

a) Cut finger on lawn-mower blade

Impacts

a) Thumb injury when thrown forward onto facia of vehicle during heavy breaking

b) Slight bruising due to safety belt } Vehicle collision

c) Sprained ankle

Electrical

a) Shock caused by reaching into back of transmitter and touching EHT terminal

b) Shock from un-discharged capacitor

c) Burn due to heating of metal arm-band which made contact with 50V dc supply

d) Shock from telephone made electrically live when lightning struck mast.

The noticeable difference between the 1974/75 list and those of previous years is the number of electrical accidents, each of a different nature but each typical of one aspect of risks associated with routine IBA operations.

Back injuries due to lifting are known to be quite common although usually not directly associated with any specific action and thus not reported as an accident. One vehicle collision resulted in two injuries, as noted. Twenty-five other incidents were recorded, mostly minor, and none causing personal injury.

The common factor in almost all the reported accidents was that they were due to hasty actions – hurrying, not waiting for help, not allowing sufficient time for assessing the hazards, etc. thus highlighting the principle that *there must be time for safety*.

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